annual report
to the
nasa administrator
by the
aerospace safety advisory panel
on the
space shuttle program

part II—summary of information

ALT flight readiness

OFT development status

march 1977

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ANNUAL REPORT TO THE NASA ADMINISTRATOR

by the

AEROSPACE SAFETY ADVISORY PANEL

on the

SPACE SHUTTLE PROGRAM

Part II - Summary of Information Developed in the Panel's Fact-Finding Activities

March 1977

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I. INTRODUCTION

The Panel focused its attention this past year on those areas we consider most significant for flight success and safety. Thus the Panel focused on the elements required for the Approach and Landing Test Program (ALT), the Orbital Flight Test Program (OFT), and those management systems and their implementation which directly affect safety, reliability and quality control.

To manage our limited manpower effectively in terms of our priorities, we have organized our ten members and consultants into task teams for specific areas of ALT and OFT.

The number of individual fact-finding sessions conducted by the individual Panel members and by larger groups within the Panel averages four or five a month. Such fact-finding is conducted principally at NASA sites and at contractor and subcontractor plants, and as appropriate with other government agencies such as the United States Air Force.

In the process of fact-finding and inspection, the Panel has reviewed considerable detail which is summarized here so the reader can understand the data base upon which Volume I is based. This data base includes doumentation reviewed in preparation for review as well as the questions and answers of the reviews themselves. Because the Panel review is on-going, special addendums are incorporated in each section to assure the reader has the most update material upon which

to evaluate the current posture of the program and its elements.

The task teams and their objectives are outlined here.

A. Approach and Landing Test Program (ALT)

1. Management System for Mission Planning

The objectives of our reviews in this area is to assess the degree to which:

a. The program management system has defined a set of mission rules that provide a reasonable basis for confidence that the normal flight plan can be successfully executed.

b. The flight planning process has used a conservative approach in planning the nominal mission and providing for contingency and abort situations including emergency separation and jettison.

2. Management Systems for Certification of the Flight Vehicles

The objectives of our reviews in this area are to assess the degree to which:

a. Both vehicles are being subjected to a rigorous system of reviews to assure they will meet mission certification requirements.

b. There has been a satisfactory program of test and analysis to assess the mated configuration in terms of mated aerodynamics, performance and flight controls or to their effect on structures and pilot control.

3. Management System for Certification of the Avionics System

Because of the significance of this system, one of our members dedicates his efforts to monitoring the development of the hardware and software and their integration into a flight system.

4. Management System for Facilities, Communications and Ground Support Equipment.

The objective of our review is to assess whether the test and simulation program appears to be adequate to demonstrate the ability and reliability of each of these elements to support the mission requirements.

5. Management System for Risk Assessment

The objective of our review is to assess the system for the preparation of the ALT Project Mission Safety Assessment Report and management's review of the risks being accepted for these flights.

A second objective is to assess the configuration management system which should assure that the hardware as built is the same as the design on which risk assessments are based.

B. Orbital Flight Test Program (OFT)

The major elements that are not being tested on ALT are the Main Engine, External Tank, Solid Rocket Booster and Orbiter Thermal Protection System. Because of the significance of these elements for the success and safety of OFT we have dedicated member monitoring and evaluating their development and manufacture.

1. Space Shuttle Main Engine (SSME)

The dedicated member monitors both component and all-up engine development testing and the resolution of specific high-risk problems as they arise. The objective of our review is to assure that the management system is developing an adequate basis for flight certification. The interaction of the engine with the Orbiter,

External Tank and Solid Rocket Booster is also considered.

2. External Tank

The purpose of the review here is to consider those areas that might cause the OFT and operational flights to be below nominal expectations. Areas that receive attention include the structural adequacy of the tank, the external insulation and its ability to support the SSME operation and Orbiter/ET separation. Reviews also focus on the tests such as the Main Propulsion Test and Ground Vibration Test.

3. Solid Rocket Booster

Since the objectives of the reviews in this area are to assess the reliability of these critical elements, particular attention is given to the launch and ascent, structural integrity of the Solid Rocket Motor, adequate/reliable performance from the APU's and the thrust vector control system. Since these units are subjected to repeated use, the Panel also focuses on the systems for recovery and refurbishment.

4. Orbiter Thermal Protection System (TPS)

The significance of this new method of protecting vehicles during return from earth orbit prompted the Panel to assign this area to a dedicated member. The objective of our review is to assure that the TPS meets the aerothermodynamic requirements to assure that a safe return is accomplished. This includes an examination of the management, test programs, installation and maintenance activities, and the interface effects between TPS and other Shuttle elements.

II. THE APPROACH AND LANDING TEST PROGRAM

A. Introduction

The Approach and Landing Test Project (ALT) is scheduled to begin February 18, 1977. It is now scheduled for completion in time for the Orbiter to be delivered to MSFC by March 17, 1978 for use in the Shuttle vehicle ground vibration test program.

The purpose of this section of the report is to provide an introduction to the management system. This then provides the lead-in for the following sections of the report covering the flight and ground hardware/software and facilities.

B. Observations

1. ALT Documentation and Utilization

The ALT program is considered a Level III or "project" element of the Shuttle program but it combines the Orbiter, the Shuttle Carrier Aircraft and numerous ground facilities and GSE. Therefore, a number of Level II requirements must be applied to the management and flight associated with the ALT work. Some major items are noted below:

a. "Program Structure and Responsibilities," Volume II, JSC 07700, October 21, 1976. This document defines the overall program in terms of organizational and work breakdown structure and describes the responsibilities of the major program participants. All the Space Shuttle Program Directives issued by Level II are listed. Many of these have a direct bearing on the ALT Program, e.g., (1) #1A "Space Shuttle Program Simulation Planning," (2) #21 "Space Shuttle Program

Flight Test Program Panel," (3) #66 "Space Shuttle Program ALT Flight Techniques Panel" issued June 23, 1976.

b. "Shuttle Master Verification Plan," Volumes I and II, JSC 07700-10-MVP-01 Rev. A. This detailed plan covers the ALT program, establishes and documents the approach, requirements and plans for verification of the Shuttle system for operational use.

c. "Flight Test Requirements," Volume I and II, JSC-08943 which cover: Volume I - Shuttle Carrier Aircraft, and Volume II - Orbiter Approach and Landing. Volume I has the flight test requirements necessary for the qualification of the NASA 747 (N905NA) aircraft as an air launch platform for the Shuttle Orbiter Approach and Landing Test program. This volume also includes the verification requirements for the qualification of the 747 as a long-range ferry carrier. Volume II has the flight test requirements necessary to verify the free-flight subsonic airworthiness of the Orbiter and the pilot-guided and an automatic systems approach and landing capability.

d. "Approach and Landing Test Mission Objectives Document," JSC 09918, dated September 30, 1976. This document establishes the number and sequence of flight tests to be conducted during the ALT program and includes basic objectives and flight test activities for each test.

e. Management of the ALT process and operations is described in a system of specific directives and instructions:

(1) The objectives and scope of Approach and Landing Test Program Directives (APD's) can best be described by a quote from APD

No. 001 (Rev. 1), dated November 2, 1976. "A system of ALT directives is established for providing management direction from the ALT Manager to the NASA and contractor elements involved in ALT. APD's and Management Instructions (MI's) will be issued to supersede those parts of the ALT Project Management Plan and the Ground Operations Management Plan which no longer apply."

(2) ALT Management Instructions document procedures and agreements between two or more ALT elements which have been approved by the ALT Manager. They address the operational matters involving internal and external organizational interface requirements, the procedural requirements in effect, and the duties and responsibilities of the organizations involved. Almost sixty (60) have been published.

2. The Flight Techniques Panel (FTP)

This Level II operation was established under authority of Program Directive No. 66 issued June 23, 1976. This panel provides a forum to coordinate the efforts of those involved in the development of flight techniques for trajectory, attitude control, and avionics systems management. The FTP is now a part of Flight Director's Reviews.

One of the more interesting products of this group is a set of memoranda called "ALT Flight Technique Briefs" to support the development of flight mission rules and the flight data file. These widely distributed briefs deal with very specific ALT issues where there should be a clear and common understanding among all those involved on the ALT work or where additional work is requred that must be handled in an expeditious manner. Each contains background,

specific techniques, and any open issues that may exist at the time. ALT Flight Techniques Brief #1 on "APU Consumables Management" is described in Table II-I as an example.

The Panel was particularly interested in such topics as:

a. Since tailcone-off flight control system limits are loaded into the computer memory (called I-load requirements), the Panel seeks to assure that the values of I-load are compatible with the planned inflight flight control system checks and with the Flight Test Requirements.

b. The degree to which the mated or Orbiter aero data bases should be updated between ALT flights is under review. An area of interest is the determination of the size of an effort to validate and update a selected subset of parameters or candidate list of parameters, and the form in which the data would be required, as well as the minimum turnaround time that it would take.

c. The Panel's reviews considered the methods for ground/flight crew confirmation of separation, mated performance penalty variations with atmospheric temperature conditions, the flutter envelope for the Orbiter with no hydraulic power restraining the control surfaces, ALT weights and c.g.'s.

3. Flight Profiles

The individual ALT flights are being meticulously planned in every known detail to assure the greatest return while conducting the missions under the safest of conditions. An example of the ALT mission calculations is shown in the "sample" sheet designated as

Table II-II. A sample of the ALT Free Flight Profiles and timelines is shown in Figures II-1 and 2.

4. ALT Review System

The procedures for certifying the flight and ground equipment and personnel for the ALT missions follows the basic system used on prior manned programs. Modifications have been made to meet the specific requirements of this flight program. The major review system includes the Design Certification and the Flight Readiness Reviews. In each case the work goes on for many months and culminates in a series of formal "board" meetings at higher and higher levels of management. In addition to these certification reviews the Orbiter systems have been going through an extensive test program and the results have been monitored and evaluated through a series of Customer Acceptance Readiness Reviews or Configuration Acceptance Reviews.

The ALT Design Certification Review had two phases. The first phase consisted of a project Center level review in November. The second phase provided a report to a senior Space Flight Management Board chaired by the Associate Administrator for the Office of Space Flight. This was conducted on December 9-10, 1976 at JSC. The early February ALT Flight Readiness Review (FRR) will provide management another opportunity to assess the readiness of the "as built" hardware/software for the first ALT mission. There will be subsequent FRR's for such major milestones as the first captive flight (February 1977), first manned captive flight (May 1977), first approach and landing mission (July 1977), and the first flight with tail-cone off (November 1977).

Since all of the review effort is directed toward flight readiness, it is worthwhile to indicate what the FRR is expected to accomplish in terms of (1) what the FRR should answer, (2) who must assess and certify readiness, and (3) the areas of review.

What the FRR Should Answer

(1) Has all applicable hardware and software been verified ready for the next ALT flight phase?

(2) What problems have been encountered since the previous review and what are the remedial actions being taken, and will they accomplish the job?

(3) Are the flight crews and flight control teams ready to conduct the mission from the viewpoint of nominal and possible off-nominal conditions?

(4) Are the ground support teams prepared and ready?

(5) At the "L-2" (launch day is "L") meeting, what are the remaining actions to be taken prior to actual flight?

Who Is To Make The Assessment and Certification

Usually the same organizations that have accomplished the Design Certification Review in a two phase review just as the DCR.

Review Areas

All those covered by the Design Certification Review plus the operational readiness of the flight crews, flight control teams and the ground support teams.

5. NASA Acceptance of Orbiter 101

As noted before, the ALT missions are scheduled for completion in

time to meet the scheduled movement of the Orbiter to MSFC for major test programs there. Such movement requires a formal NASA acceptance decision transferring the vehicle from contractor ownership to NASA ownership, the form used is designated as Form DD-250. The uniqueness of the reuse of the Shuttle Orbiter leads to a somewhat different arrangement than that used on past space programs and is worth noting.

(1) Rockwell International, the contractor, is responsible for the Orbiter 101 until the ALT program is completed. Thus the DD-250 accepting the Orbiter as NASA property will occur at DFRC at the end of 1977 or the first month of 1978.

(2) The Orbiter would then be returned to Rockwell International as Government Furnished Property (GFP) so that they may accomplish those modifications needed to meet the requirements of the MSFC test programs (Vibration type tests).

(3) Upon completion of the MSFC test program the Orbiter 101 will be returned to Palmdale for, as GFP, for modification to the operational configuration. This then will be delivered to DFCR for delivery to KSC. NASA then accepts the modifications to its GFP.

(4) On the other hand the Orbiter 102, to be used on the OFT flights, will be formally accepted by NASA, with proper DD-250 forms, when it is ready to leave Palmdale to go to DFRC. It will then be transferred to KSC by means of the 747-ferry aircraft.

This method of control should reduce the paperwork to a minimum and allow for more complete and timely configuration control.

TABLE II-I

ALT FLIGHT TECHNIQUES BRIEF #1

APU CONSUMABLES MANAGEMENT

BACKGROUND

The baseline APU management plan is designed to keep a minimum of two APU's running in the pressurized mode (3000 psia) from takeoff -11 minutes through rollout, and for all three systems to be in the pressurized mode for critical periods of mated flight and throughout free flight. This keeps fuel consumption at a minimum, while providing sufficient safeguards against flutter and the potential structural problems it can produce. Running three systems continuously is the desired mode of operation, but current fuel consumption data indicates that this may not always be practical. A minimum of two systems will be pressurized at all times due to the fast flutter onset following the loss of the last hydraulic system in the high pressure mode. Two systems operating in the depressurized mode (500-1000 psia) will not be relied upon to prevent flutter. While flying with two systems pressurized and one off, the crew will respond to a failure of one of the active systems by commanding on the third system.

The time required for the APU to come up to speed and bring its hydraulic system to full pressure is two to three seconds. Three switches must be thrown, the fuel tank valve to open, the hydraulic pump pressure switch to LOW, and the APU control switch to START/RUN for an APU to be brought on-line. The APU heater switches will be in auto and the controller power switch ON even when an APU is off line. Once the APU has started, the hydraulic pump pressure switch will be set to NORMAL. Hot starts present no problem if the catalytic bed is maintained at operating temperatures.

For real time planning purposes, it should be noted that the APU's burn approximately 2.30 lbm/min or 138 lbm/hr. Each of the three tanks contains 295 lbm, including an unusable plus uncertainty of 30.5 lbm. This equates to a run time of approximately 115 minutes for each APU. Since there is no crossfeed between the three hydrazine tanks, the APU's must be operated alternately to achieve the maximum duration two system capability. It must be stressed that these numbers are functions of many variables not yet completely determined (i.e., altitude profile, hydraulic pump efficiency) and will be updated as hardware testing and mission planning continue.

Three acceptable techniques have been identified for managing APU fuel. Plan A (see enclosure 1) involves switching the three systems on and off to approximately balance their operations and cause all three to reach the fuel redline (unusable + uncertainty) at the same time. Plan B (enclosure 2) involves depleting system 2 or 3 down to the redline (30.5 lbm) level and completing the mission on the remaining system (2 or 3) and system 1. Plan B will support a longer mission since the

maximum return allocation for the depleted system can now be in effect distributed between the remaining two systems. Plan C is the straightforward technique of powering up all three systems for the entire mission. When the final APU hardware data and mission profiles are acquired, a decision will be made as to which plan to use for each flight. Plan C is the most preferable approach and Plan A is the second choice. The most preferable plan that will support the normal mission duration plus a 20-minute contingency will be selected on an individual flight basis.

SPECIFIC TECHNIQUES

In Plan A (see enclosure 1) system 1 is left off initially and the longest of all three, since it is the most heavily loaded and, therefore, runs out of fuel the fastest. It is then alternated with system 2 until approximately five minutes prior to pitchover when all three systems are turned on. All three systems are left on until the abort maneuver is complete or until three minutes after touchdown if a separation is performed. If an abort is performed, system 3 is turned off after the abort pull-up and sequencing continues until five minutes prior to the next pitchover. Assuming the enclosure 1 timeline is followed, Plan A as described will cause the switching valves to be cycled 16 times during a flight.

Plan B (see enclosure 2) involves depleting system 2 or 3 by running it continuously until it reaches the unusable + uncertainty level. The other two systems are alternated as necessary to keep their fuel reserve balanced and to have all three running for separation attempts and/or free flights. The fuel normally brought home in one system is distributed between the other two and thus a longer duation is achieved at the cost of a slight reduction in failure tolerance. Assuming the enclosure 2 scheme is followed, the switching valves will be cycled 17 times.

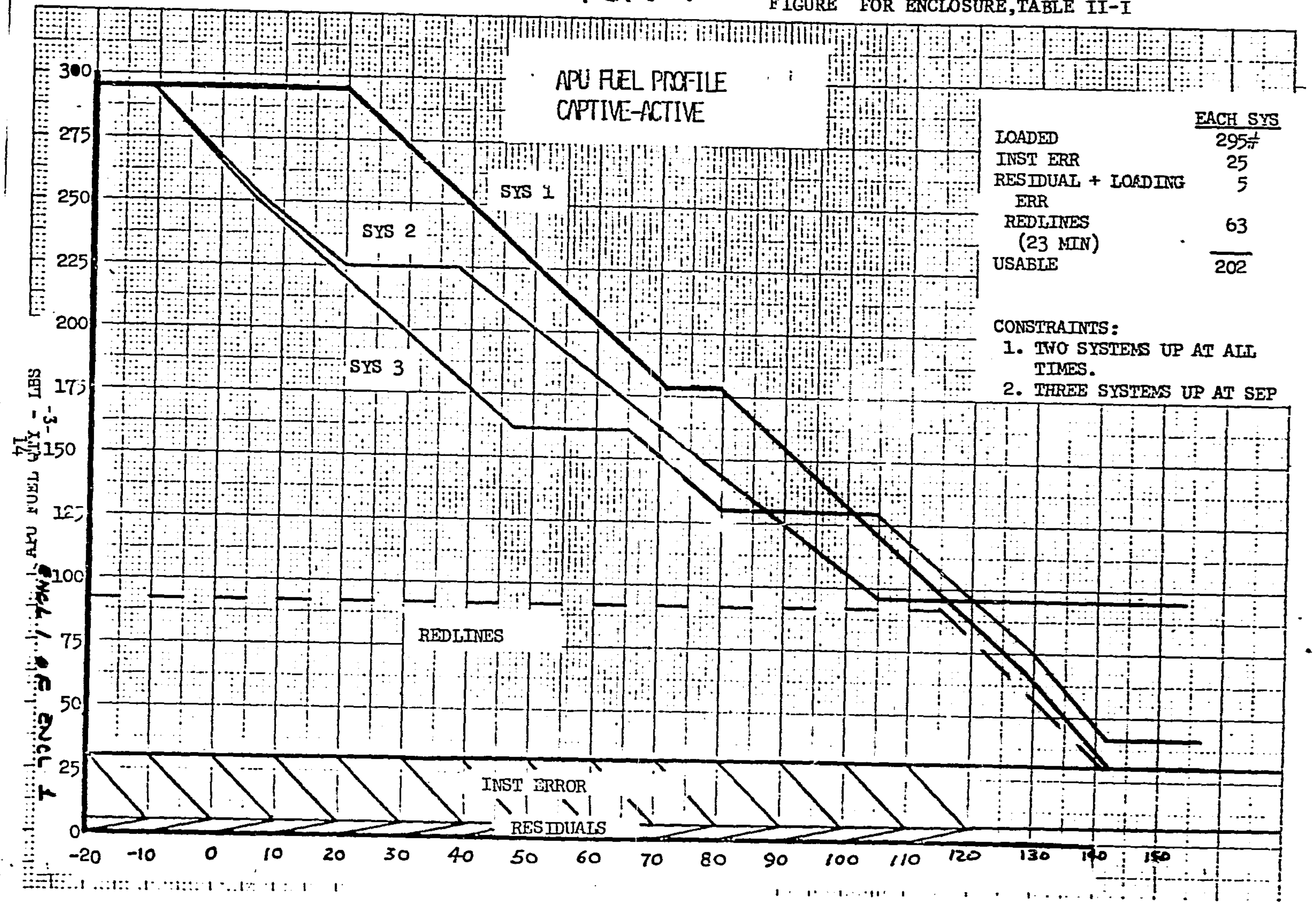
Using current specific fuel consumption data plans A, B, and C can support 142, 160 and 105 minute APU missions respectively. Current mission durations (APU) vary between 107 and 123 minutes (20-minute reserve included).

OPEN ISSUES

- Rockwell is studying a potential problem concerning cold hydraulic fluid in the lines to the actuators. There is some potential that each system will have to be flowed for a period of time prior to SCA takeoff and that an APU management plan that calls for a system to be powered down in flight would also carry a minimum flow cycle requirement to preclude cold spots in the loop.

PLAN A

FIGURE FOR ENCLOSURE, TABLE II-I



ENCL. 1 OF ENCL 1

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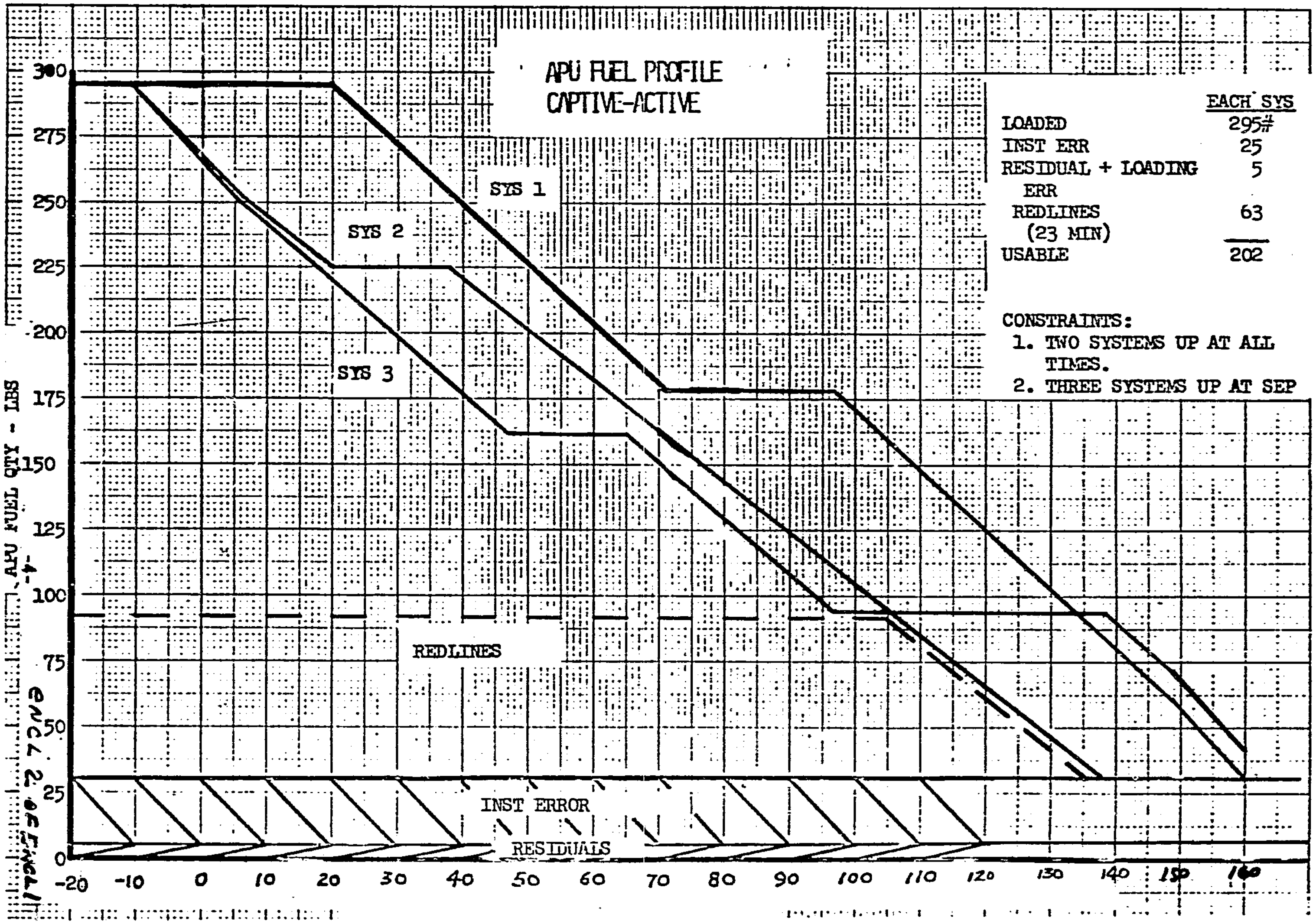
PLAN B

FIGURE FOR TABLE II-I



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ENCL 2 OF ENCL 1

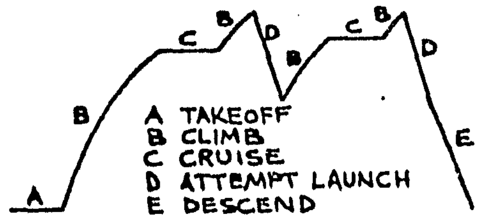
TABLE II-II

SAMPLE A.L.T. MISSION CALCULATION, DOUBLE LAUNCH ATTEMPT

JT9D-7AH Engines

Tailcone On

TAKEOFF WT.	558,912 LB
ZERO FUEL WT. AT LANDING	484,400 LB
CRS WEIGHT AT LANDING	150,000 LB
FUEL LOAD	73,700 LB
TEMPERATURE	Standard Day
FIELD ELEVATION	2,300 FT
ORBITER INCIDENCE	6°

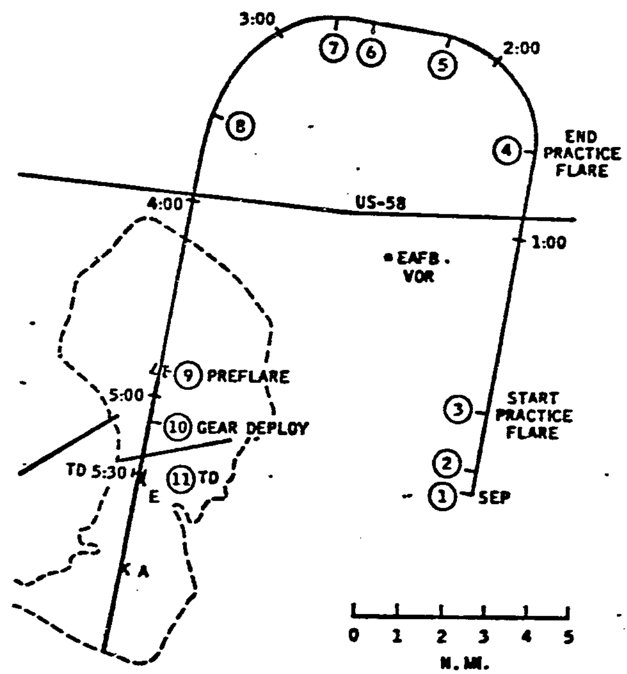


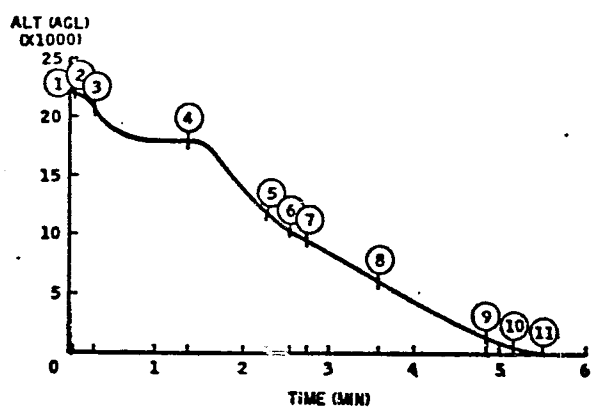
MISSION SEGMENT	FUEL BURNED (LB)	WEIGHT AT END OF SEGMENT* (LB)	ALTITUDE AT END OF SEGMENT (FT)	TIME (MIN)	DIST (NM)
TAKEOFF ALLOWANCE	3,500	554,600	3,800	21.0	0
CLIMB TO 200 FPM CEILING	18,200	536,400	25,600	26.2	125
CRUISE (15 min @ M .48)	7,500	528,900	25,600	15.0	75
CLIMB TO 200 FPM CEILING @ SPECIAL RATING	5,100	523,800	28,000	8.3	40
LAUNCH ATTEMPT	500	523,300	19,000	2.0	10
CLIMB TO 200 FPM CEILING	8,800	514,500	26,600	15.0	70
CRUISE (15 min @ M .48)	7,000	507,500	26,600	15.0	75
CLIMB TO 200 FPM CEILING @ SPECIAL RATING	4,800	502,700	29,200	8.4	45
LAUNCH ATTEMPT	500	502,200	19,000	2.0	10
DESCENT	700	501,500	2,300	6.3	30
TOTALS	56,600			119.2	480
RESERVES					
1/2 HR HOLD	13,400	488,100			
5% of INITIAL FUEL	3,700	484,400			

* EXCLUDES ORBITER CONSUMABLES OF 812 LB WHICH ARE INCLUDED IN TAKEOFF WEIGHT ONLY.

ALT FREE FLIGHT 1

ITEM	TIME	ALT (AGL)	KEAS	α	θ	ACTION
1	0:00	22100	260	10	.5	SEP; $\dot{\delta}$ = 2°/SEC, 3 SEC; $\dot{\delta}$ = 0, 2 SEC
2	0:05	21900	250	7	6.5	ROLL RIGHT ϕ = 20°; $\dot{\theta}$ = -1°/SEC AT θ = -5° ROLL ϕ = 0; CONTINUE $\dot{\theta}$ = -1°/SEC TO θ = -10
3	0:18	20400	270	6	-10	AT AS = 270 INITIATE PRACTICE FLARE $\dot{\theta}$ = 2°/SEC; CONTINUE FLARE TO HOLD $\dot{h}$ = 0, AS = 185
4	1:25	17900	185	11	11	AT AS = 185 $\dot{\theta}$ = -1°/SEC TO θ = -6°; ROLL LEFT TO ϕ = 30°
5	2:15	12000	240	8	-6	AT ψ = 265° ROLL TO ϕ = 0
6	2:35	10000	265	6	-6	AT AS = 265 $\dot{\theta}$ = 1°/SEC TO θ = -2 TO HOLD AS = 270
7	2:45	9300	270	5	-2	ROLL LEFT TO ϕ = 30° TO LINE UP ON RUNWAY ψ = 175°
8	3:35	6000	270	5	-2	TURN COMPLETE HOLD AS = 270
9	4:55	900	270	5	-2	INITIATE PREFLARE
10	5:10	350	250	6	4	AT AS = 250, DEPLOY GEAR
11	5:30	0	175	11	11	T.D. AS < 220; $\dot{h}$ < 10 fps
12	5:45	0	100	--	--	AT AS = 100, GENTLE BRAKING TO AS = 80
13	6:00	0	50	--	--	AT AS = 50, ENGAGE NWS





WT = 150,000
CG = 64.5 % (1070.24)

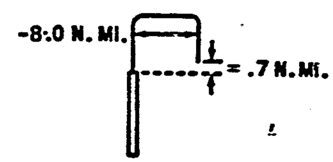
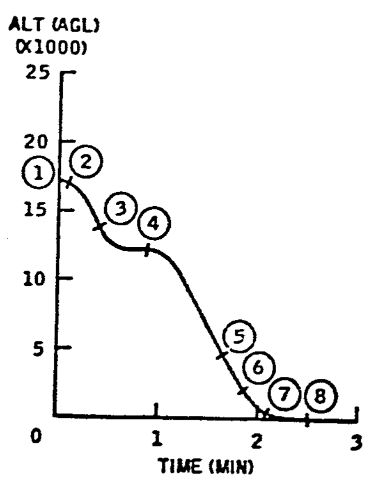


FIGURE II-1

ALT FREE FLIGHT 6

ITEM	TIME	ALT (AGL)	KEAS	α	θ	ACTION
1	0:00	17200	260	10	.5	SEP; $\dot{\theta}$ = 2°/SEC, 3 SEC; $\dot{\theta}$ = 0, 2 SEC
2	0:05	17000	244	8	6.5	ROLL RIGHT ϕ = 20°; $\dot{\theta}$ = -2°/SEC AT θ = -5° ROLL ϕ = 0; CONTINUE $\dot{\theta}$ = -2°/SEC TO θ = -22°
3	0:23	14300	255	5	-22	AT AS = 255 INITIATE PRACTICE FLARE $\dot{\theta}$ = 2°/SEC, CONTINUE FLARE TO HOLD $\dot{h}$ = 0; AS = 185
4	0:55	12200	180	11	11	AT AS = 185; $\dot{\theta}$ = -2°/SEC TO θ = -22°
5	1:40	4600	285	4	-22	AT AS = 285 $\dot{\theta}$ = 1°/SEC TO θ = -17° TO HOLD AS = 290
6	1:52	2000	290	4	-17	INITIATE PREFLARE $\dot{\theta}$ = 2°/SEC
7	2:07	350	250	6	3	AT AS = 250 DEPLOY GEAR
8	2:27	0	175	11	11	T.D. AS < 220; $\dot{h}$ < 10 fps
9	2:30	0	160	--	--	BRAKE AS REQUIRED



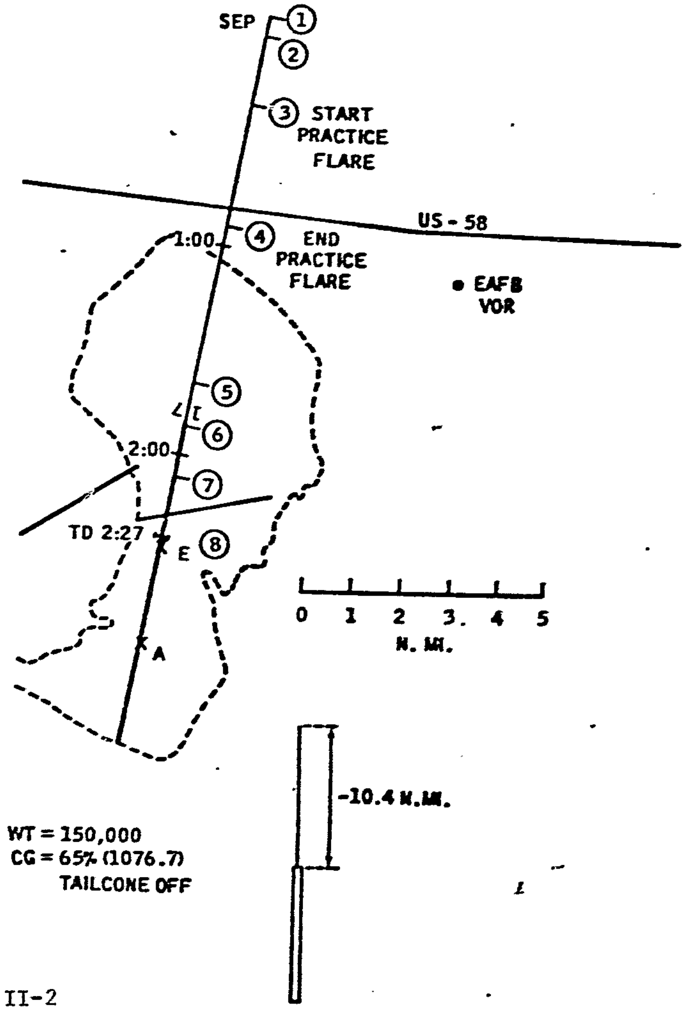


FIGURE II-2

III. ORBITER 101

A. Introduction

The first flight Orbiter (101) has been subjected to a management review process as systematic as the ones on prior manned flight programs. The progress of the design has been critiqued through a system including a Preliminary Requirements Review (PRR), a Preliminary Design Review (PDR), Critical Design Review (CDR) for all major subassemblies and finally the Design Certification Review (DCR). The progress of the flight hardware and software through the verification test program has been monitored and critiqued through a series of Customer Acceptance Reviews.

B. Observations

1. General

This section of the report discusses the Orbiter systems. As for the interface definition and separation monitor and control system this is shown in Figure III-1 and the mechanical system is shown in Figure III-2. These interfaces and the electromagnetic compatibility and various hardware/software interfaces received verification by analysis, and varying levels of actual equipment testing. Mostly this verification testing was done at the system level

2. Structures

The internal program reviews and printed material have provided the Panel ample opportunity to review the structures in terms of

design requirements and verification as well as material control. The Panel has given particular attention to open work and areas of concern that need to be resolved before the ALT flights.

Briefly the structural design requirements cover the following areas:

a. Ultimate factor of safety of 1.4.

b. No skin buckling prior to entry. (OFT requirement)

c. Fracture mechancis considerations.

d. 65,000 pound payload up and 32,000 pound payload down. (OFT)

e. 350° F. maximum external skin temperature. (OFT)

f. Landing sink speeds.

g. Acoustic environments. (OFT)

There has been little difficulty in meeting these requirements except in the area of landing sink speeds and to a lesser degree the acoustic environments. These areas have received appropriate program attention during the design and test program. The landing sink speed has been specified at no greater than 9.6 feet per second with a 32K payload, and there is a requirement of 6.0 feet per second when the Orbiter has an abort landing with a 65K payload. The acoustic environment specification is 150-165dB to meet payload requirements.

Certification of dynamics requirements by analysis (SD 75-SH-0032-1) are supported by horizontal ground vibration tests conducted with the Orbiter 101. Such tests have shown minor deficiencies in the mathematical model used in the analysis. Corrections to this model are now in process and should be completed by mid-January 1977. A rerun

of the analyses can then be made, particularly with regard to flight control stability, flutter stability and loads.

There are a number of items in the process of being closed in the area of material control certification. The following items are to be completed: materials tests at White Sands Test Facility, approval of subcontractor material control plans and use, single-barrier failure analysis, review of closeout photos, material usage agreements for the off-the-shelf hardware, ground support equipment hazardous fluid review and the insertion of all materials data into the MATCO system.

Other items in the process of being resolved include:

a. Proof load test of nose landing gear door.

b. Five open RID's on the Tail Cone.

c. Tests to assess whether the Thermal Protection System on the vertical stabilizer and the Auxiliary Power System pod must be redesigned because of a possible increase in temperatures from exhaust products.

d. Certification tests on the Orbiter purge, vent, and drain components. These are small items such as clamps, screens, adapters, etc.

While the elevon seal panels have been a problem, the current work indicates these have been satisfactorily resolved. Finally, there is a large amount of work deferred from the Palmdale plant that will need to be finished at DFRC.

Orbiter 101 will carry the following development flight instru-

mentation to gather data on structural response to flight conditions:

Quantity	Type	Purpose
216	Strain Gauge	Primary Structure Response
74	Accelerometer	Structural Dynamics, Flutter
3	Microphone	Structural Dynamics
4	Differential Pressure	Flutter

3. Auxiliary Power Plant and Propulsion Simulation

The main propulsion system and the orbital maneuvering system and reaction control system are all simulated or modeled with inactive equipment. For instance the three main engines are simulated as to mass and envelope. There are stiff braces in lieu of thrust vector control actuators as well as simulated engine-mounted heat shields. The forward reaction control system is a boiler-plate module without any actual or simulated subsystem hardware. The Orbital maneuvering system and reaction control system pod contains a simulated structure to achieve the proper aerodynamic moldline, and no system hardware is required.

The Auxiliary Power Unit Subsystem (APU) consists of three independent systems that provide mechanical shaft power to the hydraulic pumps, using one pump for each APU. Each APU system consists of a fuel tank, fuel distribution and servicing system, auxiliary power unit and controller, lubrication system, exhaust duct assembly, fuel/lube oil vents and drains, and a thermal control subsystem. The fuel used is monopropellant hydrazine. The pressurizing gas is helium. There are displays and controls and sensing devices to permit the crew and

ground-based stations to monitor the operation of the overall and specific segments of the APU system. The power output to each hydraulic pump is 135 HP normal speed and 148 hp at maximum speed. Normal speed for the turbine is about 73,000 rpm. The APU operation during manned captive flight is as shown in Figure III-3, and for free flight in Figure III-4. Note that in each case the APU's are required to be shut down and restarted during the flight period. Three significant problems have to be resolved.

a. Shutdown Soak-Back Temperature. This appears to be caused by the fuel control valve response which permits burning of fuel in the exhaust area. There are several investigations in process. These include consideration of injector/standoff changes to reduce peak temperature and an assessment of the fire hazard with insulation removed and the use of a shield to allow convective cooling.

b. Low Fuel Pump Volumetric Efficiency. The bearing design and/or material causes this loss in efficiency thereby limiting peak APU horsepower. It is a time-dependent problem which means that the APU will work well for awhile and then have a drop off in efficiency. Investigation revealed that the raphitar (carbon with binder) material used for the bearing have less swell than development bearings contributing to large clearance and greater loads. Other graphitar materials swell too much and cause the bearings to seize. The approach for ALT is to machine a new bearing and match their geometry and tolerances to the "swell" characteristics of the machine. As for the long term solution, a more extensive test program is planned which

will include consideration of other materials.

c. Turbine Wheel Life. There has been a failure of an APU wheel at just under 60 hours of operation. Analysis of the failure showed that the electron beam welding machine failed to mal the necessary penetration. The wheel design and manufacturing procedures are being changed to improve producability and non-destructive test procedures are being added. These problems may impact delivery schedules for the necessary APU's for the integrated test program. There is, of course, a means of conducting the integrated tests without the APU's, but this is not desirable.

4. Avionics.

The Orbiter 101 avionics provides the flight control and automatic flight

ALT free flights as well as to support manual operations, management of the Orbiter systems, and determination of vehicle status and operational readiness. The avionics system consists of the flight control and data management subsystems on which the Panel focuses. In addition, there are the subsystems for guidance, navigation and control, crew station displays and controls, communications and tracking, electrical power and the flight instrumentation. The structure of the Orbiter 101 software is shown in Figure III-5. Verification of the avionics hardware and software is accomplished through a program of reviews, analyses and tests shown in Table III-1. The following sections briefly describe each subsystem.

a. Flight Control Subsystem FCS.

This system consists of sensors and controls providing in-

puts to the computer system which drive the vehicle effectors (actuators) and conditions the actuator command signals to assure that there is effective control and stabilization of the vehicle. This primary system is designed to meet the following safety criteria:

Level 1. Capability to complete nominal mission after one failure with normal system performance.

Level 2. Capability to return safely after a second failure and limited operation outside of design boundaries.

The hardware for this system includes what are called line replaceable units (LRU's), the crew controls, sensors, control system software, and the actuation subsystem.

The software for this system is identified in terms of software programs for specific phases of the test and flight program.

1. The VU-101 (OPS-1) program was used for early confidence testing of the FCS and support to the test program for the LRU's installed in the vehicle as well as the Horizontal Ground Vibration Tests.

2. The ADL5B (first OPS 2 delivery) is to be used for all single string testing.

3. The ADL 5 is to be used for multistring testing including verification of the FCS.

4. The SAIL dropout program is a preliminary or interim version (flt S/W) for use at the Shuttle Avionics Integration Lab in testing to support the free flight missions of the Orbiter during ALT.

5. The ALT CI is the version to be used on the ALT flights.

The Panel has given particular attention to the program to certify

the software flightworthy and lfight ready. An important part of the verification program is the "Acceptable Fault Tolerance Verification" phase. This part of the program demonstrates the ability of the system to detect failures and protect against false alarms, and demonstrates acceptable level of vehicle transients due to system failures. The subsystem stability and performance and redundancy management certification tests will be conducted on ADL/FCHL. The testing of this program provides important information on the crew's inter-action with the system that helps plan the timeline for redundancy management.

A good deal of work in the certification program remains to be completed at the time of this report. Much of it is to be done as part of the integration testing on Orbiter 101 as well as ADL, SAIL system tests and qualification tests on certain of the LRU's. Manned and automatic closed loop flight simulations are planned for ADL and SAIL as a major part of the flight control verification program.

b. Data Processing

This subsystem comprises the major processing elements for computation and control and interface linkage. This includes: (1) computers for handling the sensor inputs and performing the computations for control, guidance, navigation and data management functions, (2) magnetic tape memories for large volume bulk storage and organizational information related to individual display presentations, (3) digital data buses to accommodate the data traffic between computers and the other Orbiter subsystems, (4) remote interface units to convert and format data at various interfacing subsystems, and (5) display unites to monitor and control the orbiter and its mission by presentation, insertion or change of selected variables.

These elements of the data processing system are configured in redundant quantities mainly because of the overall avionics fault tolerance, partitioning, and functional isolation constraints. One of the major components of this system are the Multiplexer/Demultiplexers (MDM) which are used in numerous remote locations of the orbiter to handle the functions of serial data time multiplexing and demultiplexing associated with the digital data buses, and of the interface signal adaptation. These units are multipurpose bus terminals which provide compatible interfaces between the Input/Output Processors and various interfacing subsystems. All data transfer operations of the MDM are initiated and controlled by the Input/Output Processors.

There are a number of problems that are being worked at this time:

(1) The display unit has had a corona problem. The high voltage power supply has an arc path which could cause the display unit to fail. The interim fix for the Orbiter 101 is a corona shield made of Kapton tape. The effectiveness of this fix has been demonstrated by analysis and test at the vendor's facility. During test at higher temperatures (78C vs 50C) the unit ran for 1142 hours before failing. At the nominal temperature of 50°C this translates into an expected 2000 hour life. Final changes are planned for the unit.

(2) The MDM has had difficulties passing the vibration portion of the qualification tests. The vibration levels used are those for Orbiter 102. However, since the Orbiter 101 ALT environment is considerably more benign than that for the Orbiter 102 there is no expected problem during ALT flights. The final solution required for Shuttle operational flights is to pot the power supply with foam and rerun qualification. In another area of the

MDM the sequencer/sequential control unit (SCU) has had "halts" in which the MDM ceases to operate on one data bus until power is recycled. The work-around is to switch to the backup data bus. One potential contributor to the problem was a manufacturing error which resulted in some MDM's having a 5K ohm resistor in the sequence control logic. All critical MDM's have been corrected. Although this has a very low frequency of occurance it will be monitored closely during the integrated tests to assure that it is acceptable for ALT missions.

(3) A power supply failure in the central processing unit of the general purpose computer has been caused by internal shorts. The short current was sufficient to cause severe charring of components inside the unit (power supply) and the loss of the general purpose computer. The problem is under intensive investigation at this time including failure analysis, but the problem still is open for positive identification of th cause.

c. Integrated Guidance, Navigation and Control (GN&C)

The GN&C system is, of course, critical to the operation of the flight control system. The requirements for this system are depicted in Figure III-6 and the remaining activities to get the system ready for ALT are shown in Table III-II.

d. Displays and Controls

This subsystem includes the integrated arrangements of functions dedicated and general purpose display units, switches, meters, status indications, cathode ray tubes and associated keyboards and encoding-decoding-conversion electronics associated with interfacing instruments and manual controllers. It also includes the interior and integral lighting and the very important caution and warning subsystem. The caution

and warning setup provides the crew with timely alerts about actual or potential orbiter system failures or out-of-tolerance conditions. A memory is provided in this arrangement so that the crew may determine whether preselected system annunciator lights have been energized previously.

Problem areas, which are in the process of being resolved, include:

(1) The driver display unit development tests indicate that the radiated electromagnetic interference may be out of specification by as much as 24 dB at certain frequencies. This radiation level would still be about 20dB below that specified as the susceptibility threshold for Line Replaceable Units (electronic boxes). The capability for proper mission performance will be verified during the integration testing in progress on SAIL/ADL and the Orbiter, and does not appear to pose undue problems for flight at this time.

(2) The altitude vertical velocity indicator did not meet electrical susceptibility requirement. It was about 17 dB below specified level at the one frequency of 7.4KHz and this might affect the buses and possibly cause both altitude verticle velocity meters to malfunction. This will also be re-examined during integrated system test and SAIL and does not appear to pose a problem for orbiter active flights at this time.

Here again there are a number of final reports that are due in the January-to-March time frame to complete the certification program.

e. Communication and Tracking

This system consists of the radio frequency processing and dis-

tribution equipment necessary for (1) reception, transmission and distribution of Orbiter and ground-originated voice, (2) transmission of operational and DFI Pulse Code Modulated intelligence, (3) Shuttle Carrier Aircraft relay of S-band PCM data, (4) TACAN navigational aids, (5) radar altitude, (6) microwave scanning beam landing system(MSBLS),(7)C-band beacon. TACAN is usable throughout both captive andfree flight. MSBLS is usable only during the straight-in-portion of the approach. The radar altimeter provides useful data following separation at altitudes less than 5,000 feet and the 747 FM relay transceiver relays orbiter PCM data during mated flight through separation.

There appear to be no concerns regarding this subsystem at the time of this report.

f. Electrical Power Distribution and Controls

This electrical power distribution and control system converts DC power to AC power and distributes AC and DC power

all vehicle elements. Based on the verification program, the electrical power system appears to be in good shape with no single failure points that would lead directly to loss of the vehicle. There are about eleven (11) certification activities on the electrical subsystem that have to be completed in January and February 1977. These are a constrain on the inert Orbiter 101 flights and are expected to be completed prior to active Orbiter flights.

g. Instrumentation

There are two types of instrumentation systems - development

flights instrumentation (DFI) and Operational Instrumentation (OI). The DFI will be removed after the development phase of the program. The functions of the DFI are essentially the same as those of the OI, except that the emphasis is on acquisition of information for use in evaluating the Orbiter 101 performance. Instrument location and types are shown schematically in Figure III- 7 .

Development activities for the instrumentation subsystem include both testing and analysis. With the exception of off-the-shelf equipment, the development activities began at supplier facilities. The objective for suppliers was to establish confidence that the equipment design will satisfy mission requirements over all combinations of operational environments. For off-the-shelf equipment, design confidence has been established by showing that the equipment has previously been demonstrated to meet criteria that are equivalent to or more stringent than operational requirements.

5. Backup Flight Control System (BFCS).

The BFCS is functionally separate from the primary Orbiter avionics system to provide an alternative means of control in case of a "surprise" or generic problem in the multistring system. It is, therefore, a simple single string system. To achieve independence between the primary and backup systems, the software implementation of these control laws in the BFCS was done separately from the software implementation in the primary FCS. and is operated in a separate computer from the four primary computers. The software implementation is a simple design and is an adaptation of the control laws of the primary system. The operational flight program is mechanized in a straight-line fashion

with a very simple executive function. All functions except the display and pulse code modulation (PCM) outputs are scheduled at a single interation rate and in a fixed sequence. As each function is executed, operation is returned to the executive function. The functions used are: executive, flight control, displays and controls, telemetering, fault detection, error handling, input/output, housekeeping, and ground support.

The system has a separate dedicated computer, since this is a single string backup system using a simple program. The program has accepted single failure points that could cause loss of vehicle. However, this system will only be engaged if there are catastrophic software failures in primary system. The only function other than flight control performed by the BFCS is the collection, display and formating of air data computer parameters for the down-link data transmission system.

Two modes are available with the BFCS. The primary mode of operation is the command augmentation system (CAS) with an emergency manual direct mode. The CAS mode contains a down-mode capability in the event of a detected air data computer failure.

Assessment of the performance capability and design maturity of the BFCS is being accomplished through the following test program:

(1) Development tests. The Charles Stark Draper Laboratory (MIT) conducted development tests on the BFCS operational flight program to evaluate each module with all branches and end-to-end unit tests for each function. Dynamic tests were conducted to evaluate closed-loop performance of the BFCS digital autopilot and functional

capability in an F-8 Navy fighter with Shuttle dynamics. RI/SD conducted design verification tests in the Avionics Development Laboratory to evaluate software coding, linkages, support functions and end-to-end verification. They also conducted software interface and compatibility tests with line replaceable units and a single-string subsystem as well as a closed-loop test to verify subsystem operation and capability.

(2) Verification tests. JSC and RI conducted software verification tests in the SAIL. This was followed first by subsystem integration tests to verify design compatibility between software and hardware and then by closed-loop tests to verify their operational compatibility. The subsystem verification tests are now in process.

(3) Acceptance tests. The tests conducted at Palmdale checked out the subsystem copper (hard-line) path. Single-string closed-loop tests verified low gain with the air data computer off. Delta testing is in process at the time this section is written. It is to verify single-string closed-loop with the air data computer on. Integrated tests are to verify parallel system compatibility and limited ALT mission objectives because of static environments. The remaining activities associated with the BFCS include the performance of rollout simulation, complete bending compensation, reverification of the BFCS software in the SAIL, an update of the supporting documentation and a complete system verification in SAIL. The system will then be reviewed and accepted at a Customer (Configuration) Acceptance Review Board in May 1977.

6. Orbiter Crew Station.

Since the crew display and controls and caution and warning subsystem are described under the avionics section, this section will focus on two crew safety subsystem. The crew escape subsystem is to enable the crew to escape at any time throughout the entire profile of the ALT program. It also will permit the crew to escape during the ascent phase of OFT up to an altitude of 75,000 feet and a velocity of Mach 2.7. The subsystem also provides for crew escape on the pad, except where a fireball occurs.

There are two side-by-side rocket propelled seats. The ejection seat system is a modified Lockheed F-12 system. Above the seats are an inner and outer panel which are jettisoned by pyrotechnic devices. The inner panel is part of the crew module overhead integral structure, while the outer panel is part of the forward fuselage integral structure.

Figure III-8 shows the escape events, and Table III-III shows further detail on the sequence of events. The status of this system is as follows: (Production orbiters, 103 and subs do not have ejection systems)

a. The ejection panel severence system, Figure III-9 has an oversize cavity between the detonating charge and the panel. To eliminate the problems induced by excess cavity volume all production panels will be filled withRTV silicone rubber.

b. One-way transfer devices, which prevent seat ejection during emergency ground egress or rescue ingress, did not function properly and are being replaced with a previously qualified device from supplier.

Emergency ground egress for the Orbiter 101 is through the side hatch, utilizing a hatch-mounted deployable boom, "sky genie" descent devices which provide a controlled rate of descent, and safety tethers. An alternate egress procedure is provided by jettisoning the overhead ejection panels (see previous section) and using similar egress equipment stowed on the flight deck. Figure III-10 shows the primary egress method. The ground egress boom installation and descent devices verification tests and analysis report are scheduled for the last week of February 1977.

7. Environmental Control and Life Support and Power System.

The Environmental system includes the atmospheric revitalization subsystem, life support functions, and the active thermal control system. The life support functions include the water storage and smoke detection and suppression. The fire detection and suppression subsystem is required to detect smoke in the avionics bays and the crew compartment. Portable fire extinguishers are required for each avionics bay and can be actuated from the flight deck.

The major "open" items at this time include the verification analysis, scheduled for completion by February 1977 and the certification completion by March 1977.

The electrical power generation subsystem consists of three fuel cells, each rated at 7KW continuous maximum and 12KW peak power. Two fuel cells are required to provide 4.0 to 14 KW of continuous power as well as 24 KW of peak power in case one fails and the other has to handle the total demand. There is no requirement at this time for

storage batteries to be placed on board the Orbiter, although this can be done if it is deemed necessary. The electrical power generation subsystem and certification tests are expected to be complete by January 1977.

The high pressure gas storage system for the ALT provides hydrogen and oxygen fuel cell reactants. The pressure ranges are:

	Hydrogen	Oxygen
Storage, primary	2400-250 psig	2200-900 psig
secondary	2400-200 psig	2200-800 psig
Regulated, primary	350 psig	900 psig
secondary	200 psig	800 psig

8. Mechanical Systems.

Mechanical systems include the following: (a) hydraulics, (b) actuation mechanisms and surface control, (c) separation systems, (d) landing/deceleration, and (e) payload bay doors mechanism. These are shown in the schematics or outlines shown in Figures III-11, -12 and 13.

Since the payload doors will not be in use during the ALT flights the Panel has focused on the other areas.

a. Hydraulic Subsystem.

The Orbiter hydraulic subsystem consists of three independent hydraulic power systems with main pumps driven by independent APU's. The design and installation of the subsystem are in accordance with MIL-H-5440F, Type II, Class 3000 system, amended by SCN 01-0218 to the Orbiter Contract End Item Specification. The fluid distribution system utilizes titanium tubing and swagged fittings. MIL-H-83282

hydraulic fluid is used in the system as the working fluid.

The principal development and qualification problems and their resolution at the time this section is written are:

a. Leak failure occurred on the elevon actuator crossover joint quill seal during development tests. There was a non-standard seal design combined with a large misalignment.	Stepped the quill seal to reduce extrusion gap (opening of the circumference). Also provided wider seal and backup barrier seal. The modified quill successfully passed 102,000 cycle pressure-impulse tests.
b. Structural failure of the main pump front housing (case) in the fillet area where attach flange and housing meet.	Failure analysis concluded failure was caused by improper impulse test circuit setup and improper test circuit relief valve setting. Pump housing does meet requirements.
c. Filter module shutoff valve failure due to broken valve spring.	Redesigned the valve to eliminate spring.

Line resonance has not been found to be a problem but the means of verifying this is a problem.

The aerosurface actuators that are to be used in FCHL as part of testing will be the same configuration as the flight actuators except for the seals. The actuators to be used in qualification certification test will be the same configuration including the seals. Functional certification testing for the hydraulic subsystem is to be completed in March 1977. Since that system will not have the Phase II modifications, further certification testing is required on the system when those modifications have been made. This delta certification testing is scheduled to be cpmpleted by May 1977.

b. Actuation Mechanisms

Aerodynamic control surface movement is effected by hydraulically powereed actuators that position the elevons and by hydraulically powered drive units that position the body flap and combination rudder-speed brake through geared rotary actuators. Three redundant 3,000 psi

systems supply the necessary hydraulic power.

The elevon actuator or servoactuator is single balanced using two switching valves tied to the three hydraulic systems and is commanded by four independent avionic signals. Failure detection through servo valve delta pressure and piston delta pressure are used by the avionics system to detect failures and provide stable actuator operation.

Three problems can be noted:

a. The elevon actuator switching valve requires excessive time to switch to second standby system. The "trigger" valve was redesigned and successfully tested. Qualification and flight hardware are being retrofitted to the Phase II configuration with the design fix.

b. Significant leakage at the unrestrained end of the return transfer tube of actuator is due to failure of retaining pins and transfer tube displacement. A failure analysis was made and a design change approved. The retention device has been redesigned and successfully tested, and this retention device will be installed during the Phase II retrofit period.

c. Testing continues at the Flight Control Hydraulic Laboratory to understand and correct the actuator/flight control instability at 16 Hz.

Other major known problem areas are: (a) the pitting of the body flap outboard gear teeth due to improper masking fro the acid etch bath. Gears have been replaced with non-pitted teeth.

(b) rudder/speed brake motor shaft failure caused by improper test setup and procedures, since corrected and now being implemented at the Flight Control Hydraulic Laboratory at Rockwell/Space Division, and (c) Rudder/Speed Brake seal leakage and Delta-Pressure transducer strut failure corrected by redesign at Palmdale.

c. Separation Subsystem.

The separation subsystem provides the capability to release the Orbiter from the 747 carrier aircraft. This is effected by a dual frangible bolt at the forward attach point and by three frangible bolts on each of the two aft attach points. The pyrotechnically operated frangible bolt design is the same for all three attach points and is designed to separate at a predetermined section, and each uses two cartridges, each of which is capable of causing bolt separation. The certification summary is shown in Table III-IV. There are problems in certifying the flight hardware. Separation of the electrical umbilical connectors is accomplished by pull-apart connectors subsequent to the structural separation using relative separation motion to do this. Load sensors at each of the structural attachment interfaces provide the measurement of the relative loads between the orbiter and the 747 during all mated phases of the ALT missions.

Additional loads data are obtained to determine the entire flight and ground regime load envelope.

(d) Landing and Deceleration.

The major open items at this time include: (a) the need for

main gear shimmy dampling (to be determined from Bendix stability tests which are scheduled to be completed by January 1977), (b) completion of the tire certification for long landing roll (test scheduled for January 1977), and (c) off-limit testing of the brakes at 1500 psi pressure (scheduled for completion by end of February 1977).

Program safety personnel have stipulated tests that should be carried out before the system can be fully certified.

TABLE III-I

VERIFICATION OF AVIONICS SUBSYSTEMS

SUBSYSTEM	ANALYSIS	DESIGN REVIEWS	SIMULATORS	TESTING: QUAL	TESTING: ASL	TESTING: FCHL	TESTING: SAIL	TESTING: SSC/O	TESTING: ICO	TESTING: SDL
ELECTRICAL POWER DISTRIBUTION & CONTROLS	✓		✓	✓	**		✓	✓	✓	
DISPLAYS & CONTROLS	✓	✓	✓	✓	✓		✓	✓	✓	✓
INSTRUMENTATION	✓			✓	✓		✓	✓	✓	
COMMUNICATIONS & TRACKING	✓			✓	✓		✓	✓	✓	✓
DATA PROCESSING SYSTEM	✓			✓	✓		✓	✓	✓	✓
FLIGHT CONTROLS	✓		✓	✓	✓	✓	✓	✓	✓	✓
GUIDANCE, NAVIGATION & CONTROLS	✓		✓	✓	✓		✓	✓	✓	✓
BACKUP FLIGHT CONTROLS	✓	✓	✓	✓	✓	✓	✓	✓	✓	
AVIONICS SUBSYSTEM GROUP (AVIONICS SYSTEM)							✓*		✓*	✓

SSC/O = SUBSYSTEM CHECKOUT }
ICO = INTEGRATED CHECKOUT } VEHICLE

*ALL SUBSYSTEMS FULL-UP & RUNNING
**PETS/HOUSTON

TABLE III-II

INTEGRATED GUIDANCE, NAVIGATION, AND CONTROL
SUMMARY OF REMAINING CERTIFICATION ACTIVITY

ITEM	ACTIVITY REMAINING	CAR SUBMITTAL DATE
IMU	COMPLETE QUAL TEST, PREPARE & SUBMIT EAR & CAR	
GUIDANCE, NAVIGATION, & CONTROL SUBSYSTEM	COMPLETE SUBSYSTEM FUNCTIONAL & INTEGRATION TESTS, PREPARE & SUBMIT CAR PACKAGES	4-15-77 (MATED FLIGHT) 5-30-77 (FREE FLIGHT 1) 7-31-77 (FREE FLIGHT 3) 10-30-77 (FREE FLIGHT 6)

TABLE III-III

Crew Escape System - Sequence of Events

TIME (sec)*	Below 15,000 Feet	Above 15,000 Feet
0.0	D-ring pulled, panel jettisons, power shoulder reel retracts, foot actuator retracts.	Same
0.3	Catapult ignition	Same
0.55	Drogue gun deploys drogue chute	Same
0.75	Drogue chute full-open	Same
1.0	Rocket burns out	Same
1.7	Separation, lap-belt releases, shoulder straps cut, foot cables cut, D-ring cable cut, separator actuates	Separation initators armed but are blocked by aneroid device.
1.9	Drogue gun deploys main parachute	
2.0	Upper drogue chute risers cut	
3.4	Main parachute full open	
10.3	Lower drogue chute risers cut	Lower drogue chute risers cut
At 15,000 feet		Aneroid unblocks, initiating complete separation sequence, deploying main parachute 0.2 second later, and cutting upper drogue chute after 0.3 sec

* Times shown are for the right-hand seat, all events for the left-hand seat occur 0.50 seconds later

SPACE SHUTTLE ORBITER

TABLE III-IV

ORBITER/CARRIER SEPARATION SYSTEM CERTIFICATION SUMMARY

CERTIFICATION LEGEND
T = QUAL TEST
S = SIMILARITY
A = ANALYSIS

ITEM	INDUCED ENVIRONMENTS														NATURAL ENVIRONMENTS	QUAL SITE APPROVAL (QSA) COMPLETION DATE
	TEMP			VIBRA-TION			SHOCK				STRUC-TURAL				FUNGUS, OZONE, SALT SPRAY, SAND/DUST	
	HIGH	LOW	CYCLE	SINE	RANDOM	TRANSPORT	HANDLING	PYRO/SEP	ELECTROMAGNETIC COMPATIBILITY	LIFE CYCLE	LIMIT	ULTIMATE	DESTRUCTION			
FORWARD & AFT SEPARATION SYSTEM					A	A		T	A		T	T			A	1-7-77
LOAD MEASUREMENT SYSTEM	T	T	T	T	T	A	A	T	T	T	T	T			A	1-7-77
ELECTRICAL UMBILICAL SYSTEM					T	A		T							A	1-7-77
SEP BOLT	T	T			T						T	T			A	1-7-77

INTERFACE DEFINITION
SEPARATION MONITOR AND CONTROL SYSTEM

FIGURE III-1

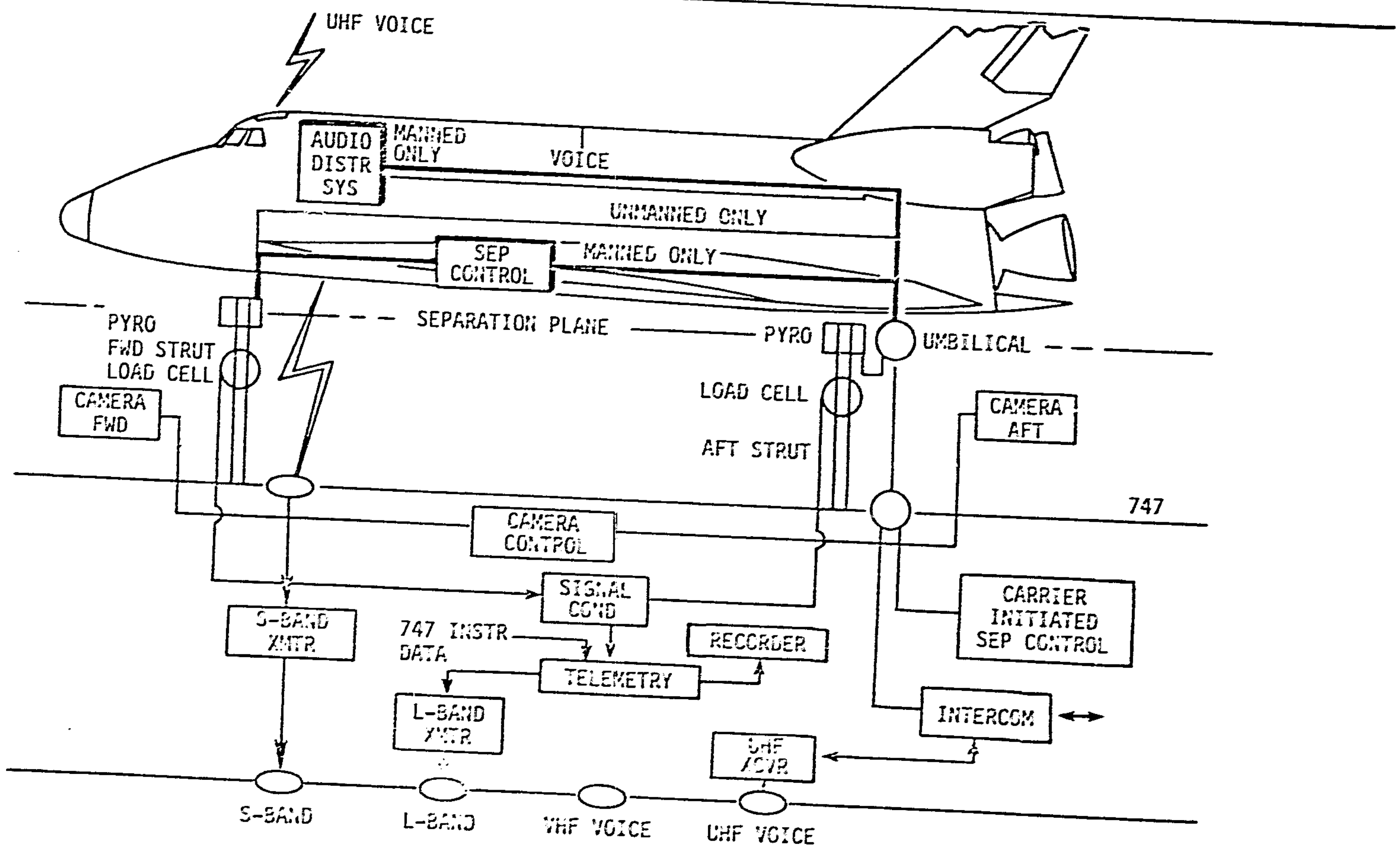
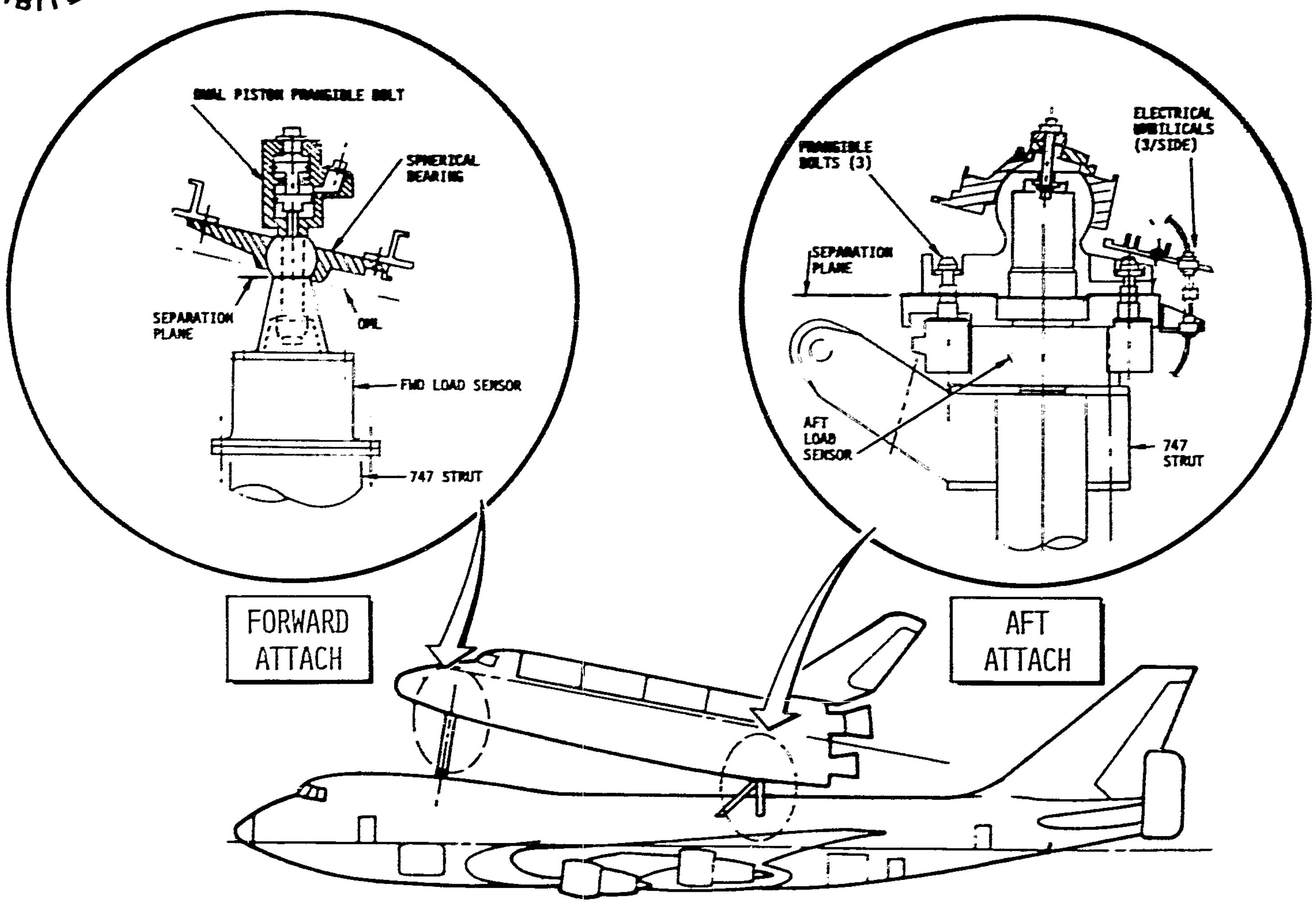


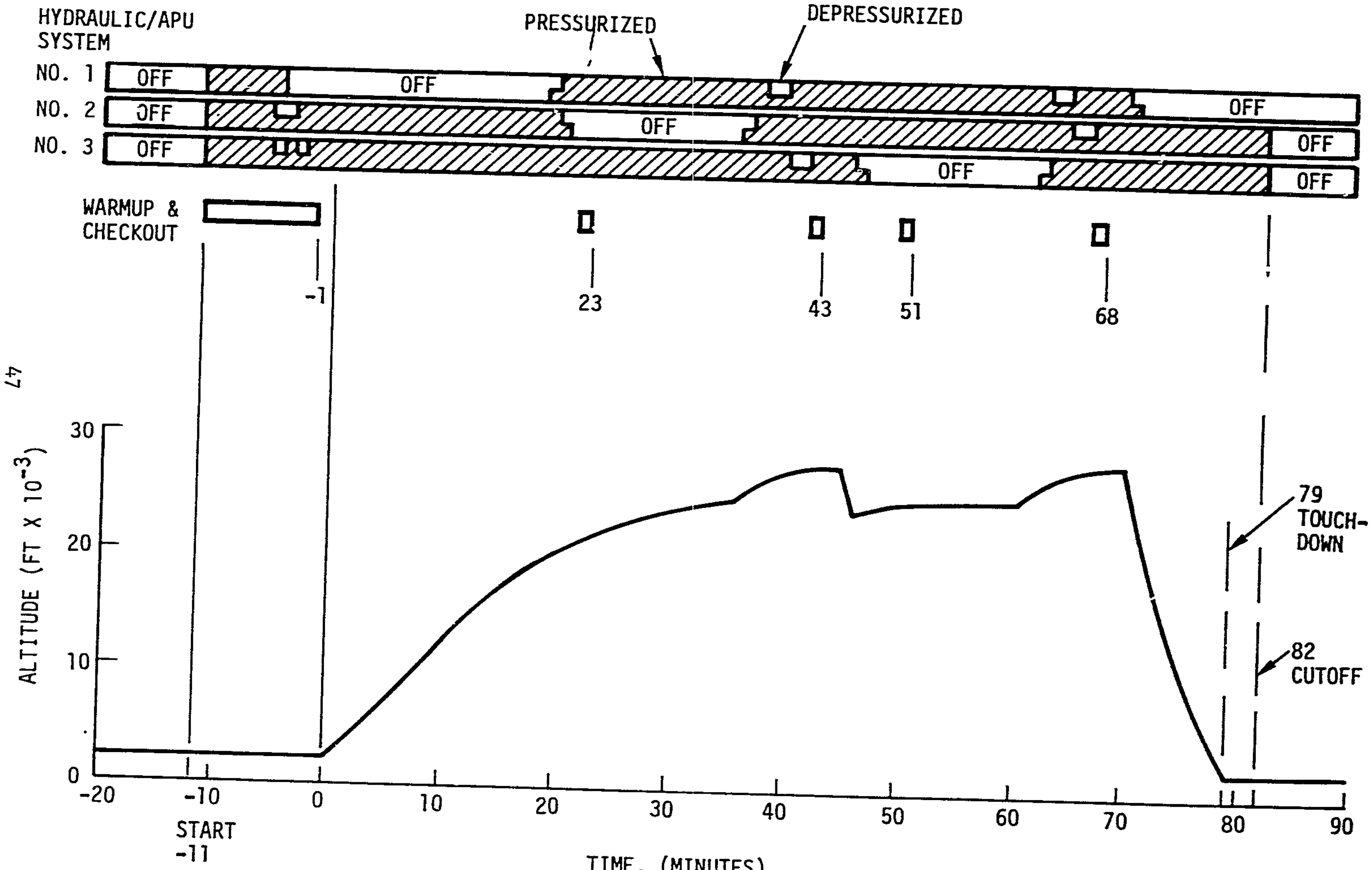
FIGURE III-2

MECHANICAL SEPARATION SYSTEM



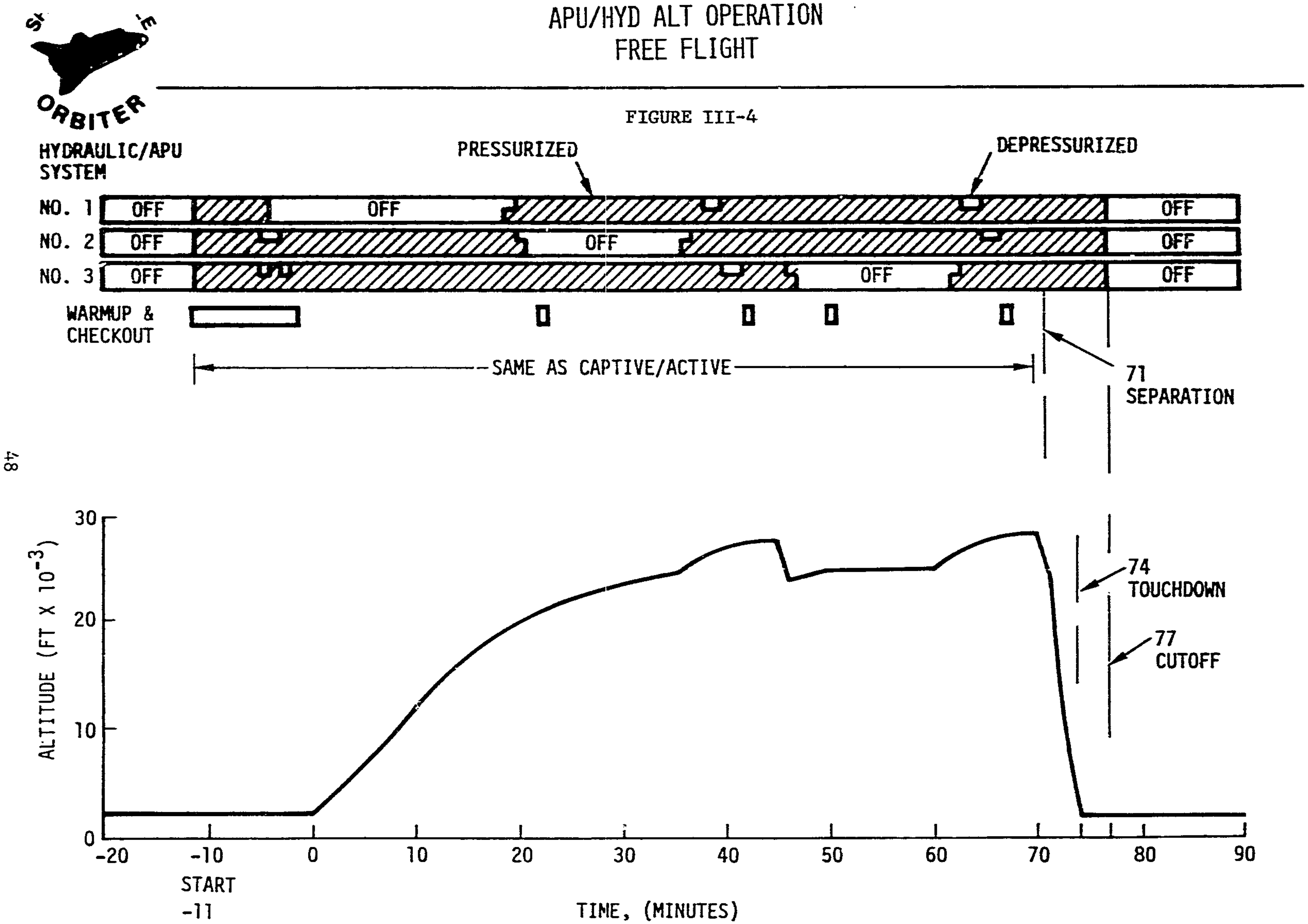
APU/HYD ALT OPERATION
MANNED CAPTIVE FLIGHT

FIGURE III-3



APU/HYD ALT OPERATION
FREE FLIGHT

FIGURE III-4



ORIGINAL PAGE IS
OF POOR QUALITY

INSTRUMENTATION EQUIPMENT LOCATION
OV 101

FIGURE III-5

(1) FWD AVIONICS BAY 1
- DEDICATED SIG COND (1)
- 01 DATA MDM (1)
- MASTER TIMING UNIT (1)

(2) FWD AVIONICS BAY II
- 01 DATA MDM (1)
- PCM MASTER NO. 1 (1)
- MAINT RECORDER (1)

(3) FWD AVIONICS BAY IIIA
- DEDICATED SIG COND (1)
- 01 DATA MDM (1)
- PCM MASTER NO. 2 (1)

(3A) FLIGHT DECK MDM (1)

(4) AFT AVIONICS BAY IV
- DEDICATED SIG COND (1)
- 01 DATA MDM (1)
- WIDEBAND SIG COND (4)

(5) AFT AVIONICS BAY V
- DEDICATED SIG COND (1)
- 01 DATA MDM (1)
- WIDEBAND SIG COND (2)

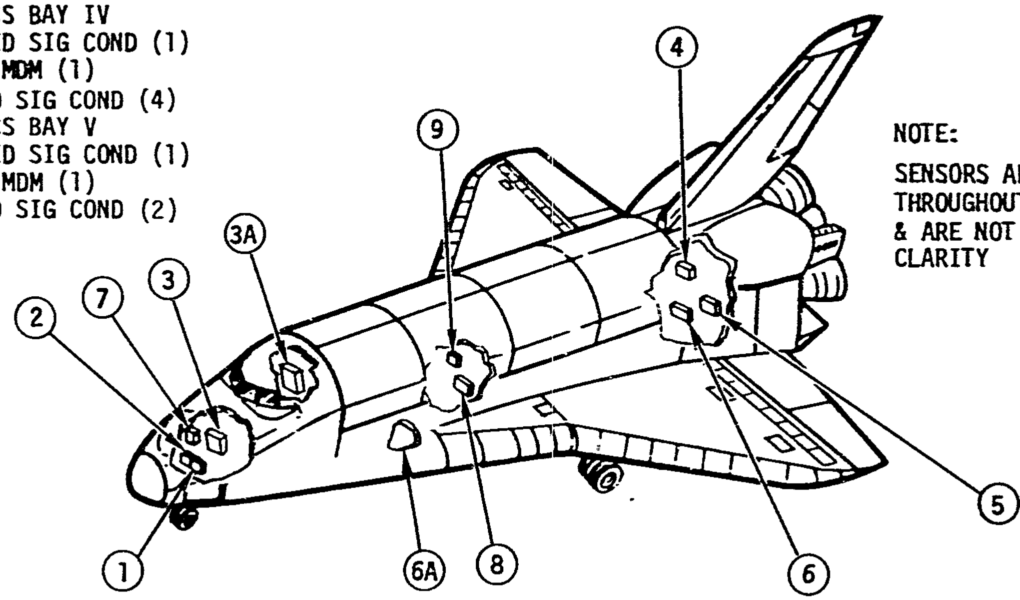
(6) AFT AVIONICS BAY VI
- DEDICATED SIG COND (1)
- 01 DATA MDM (1)

(6A) FUEL CELL DSC (1)

(7) FWD DFI CONTAINER
- S-BAND TRANSMITTER(1)
- WIDEBAND RECORDER (1)
- FDM (1)
- DEDICATED SIG COND (1)
- DFI DATA MDM (1)
- WIDEBAND SIG COND (21)
- STRAIN GAUGE SIG COND (5)

(8) MID FUSELAGE DFI CONTAINER (L)
- FDM (1)
- DFI DATA MDM (1)
- DEDICATED SIG COND (1)
- WIDEBAND SIG COND (28)
- STRAIN GAUGE COND (27)

(9) MID FUSELAGE DFI CONTAINER (R)
- FDM (1)
- DFI DATA MDM (1)
- DEDICATED SIG COND (1)
- WIDEBAND SIG COND (31)
- STRAIN GAUGE SIG COND (33)



NOTE:

SENSORS ARE LOCATED THROUGHOUT THE VEHICLE & ARE NOT SHOWN FOR CLARITY

GN&C SYSTEM REQUIREMENTS

FIGURE III-6

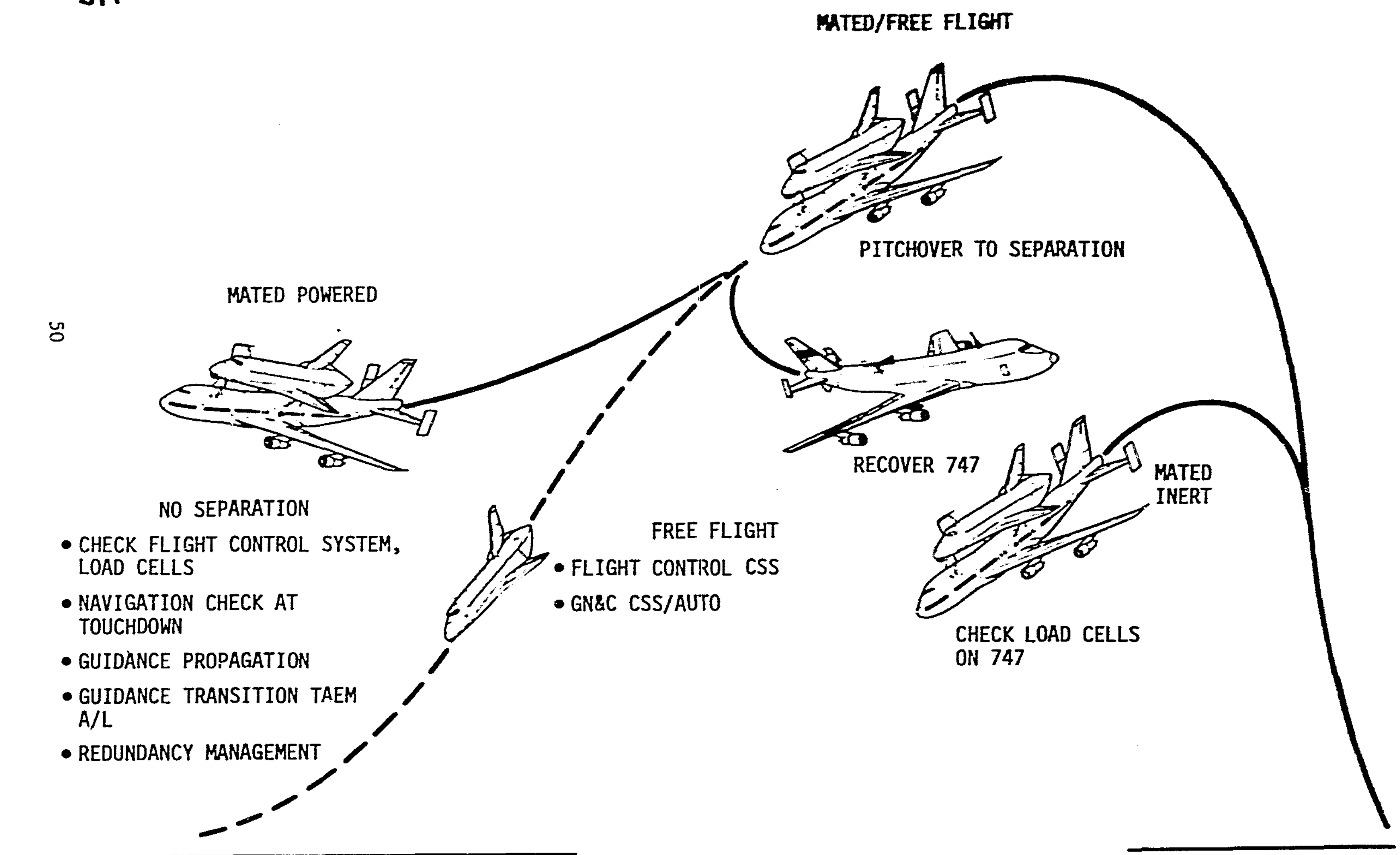
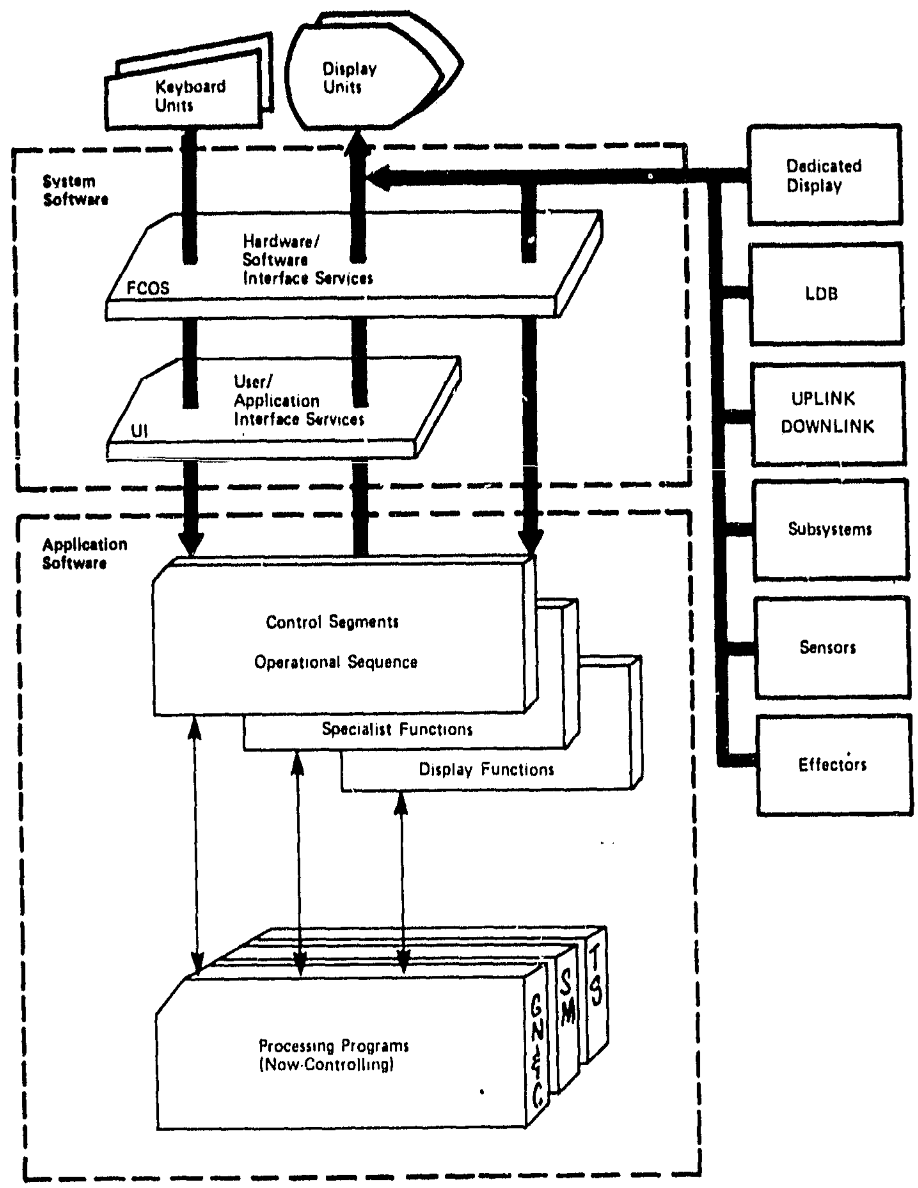


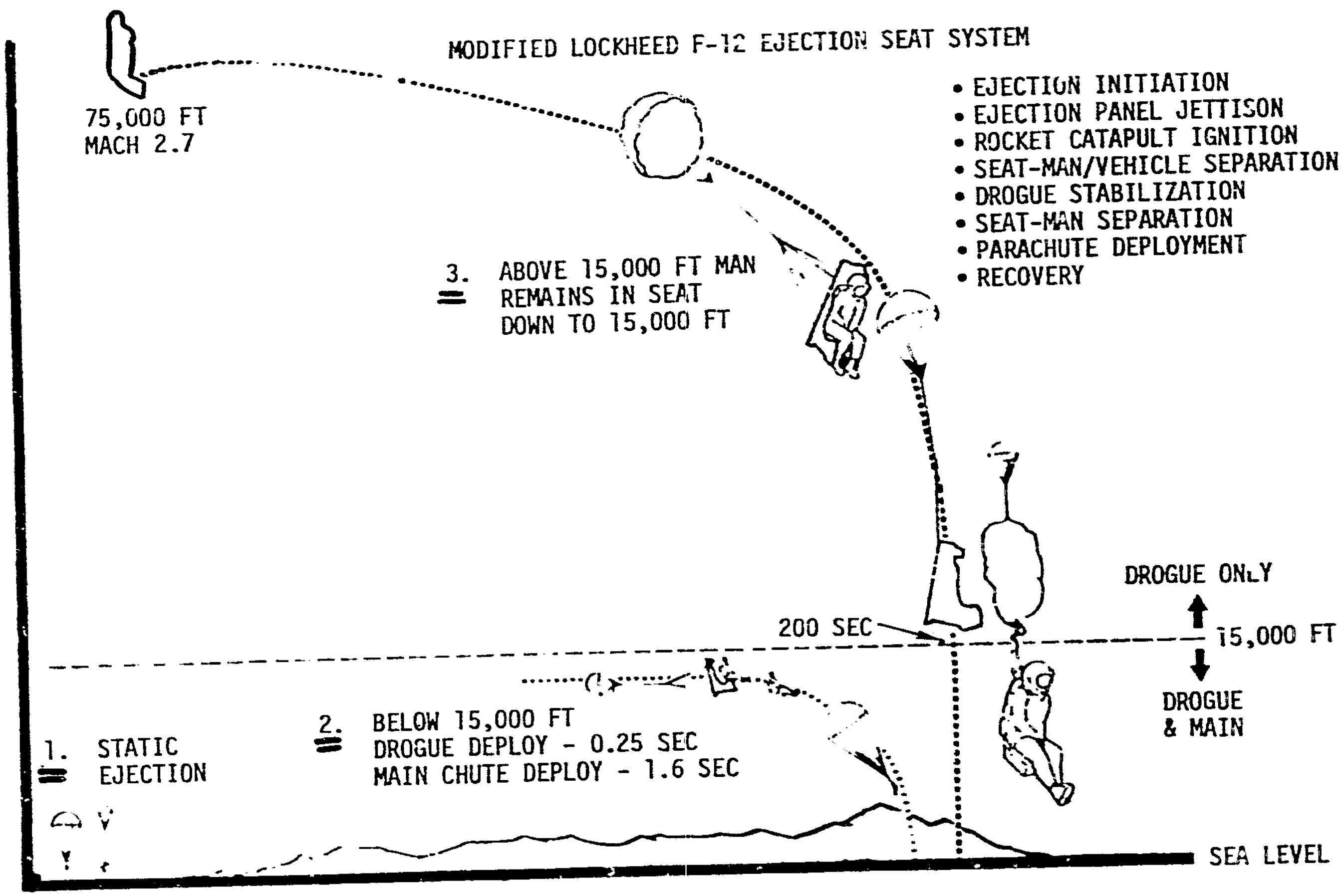
FIGURE III-7 SOFTWARE STRUCTURE



OV101 AVIONICS SOFTWARE STRUCTURE

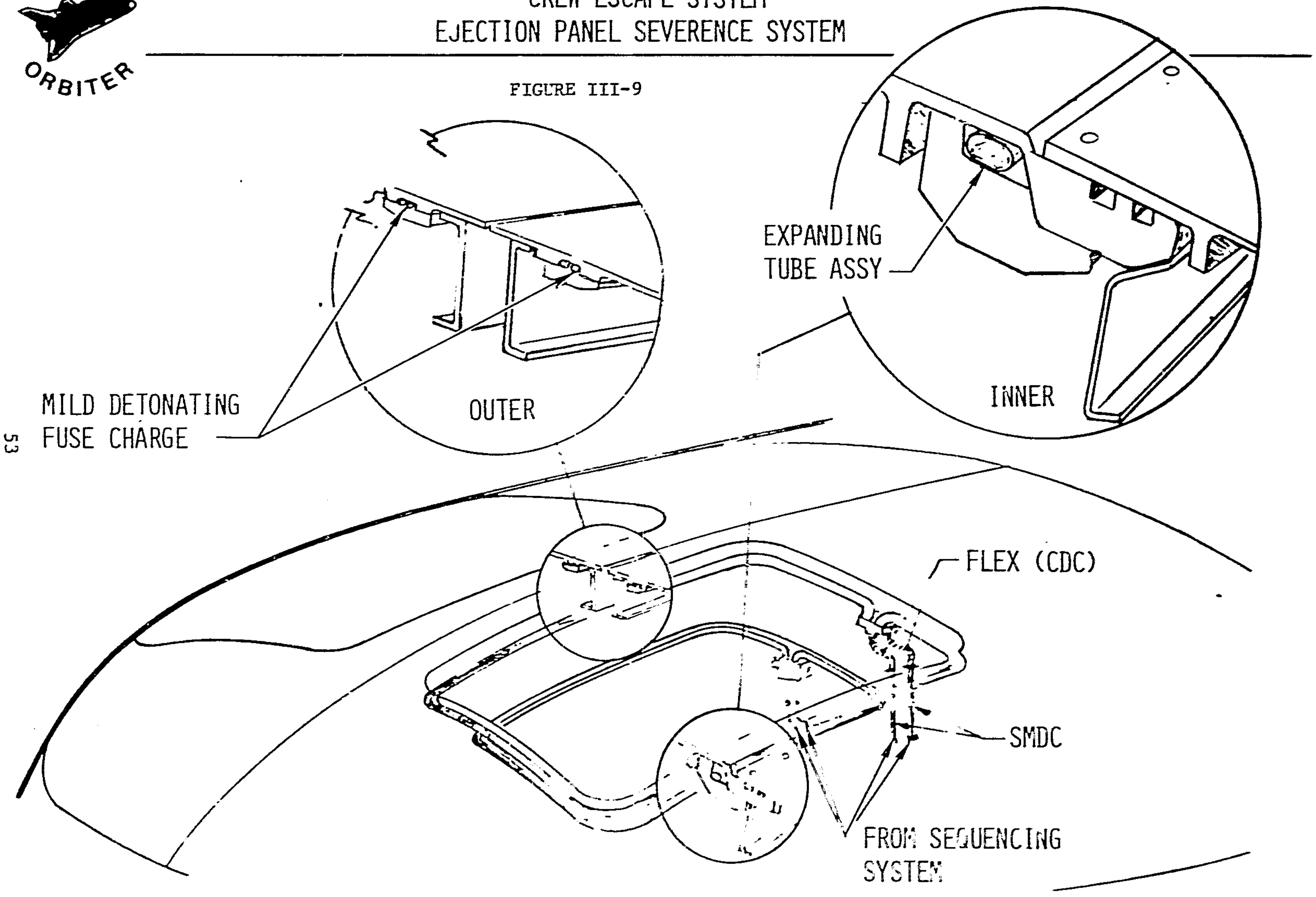
FIGURE III-8

MODIFIED LOCKHEED F-12 EJECTION SEAT SYSTEM



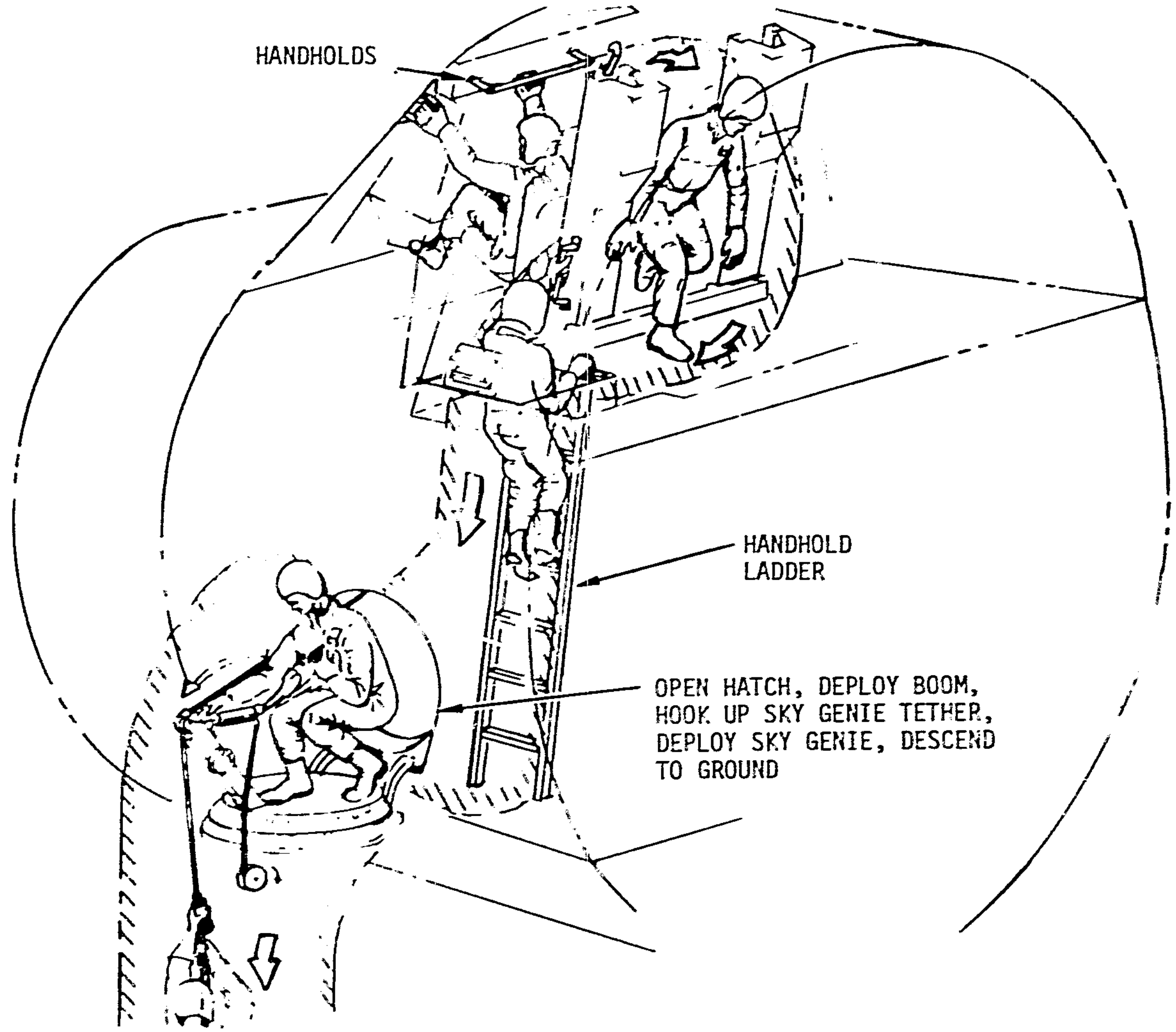
CREW STATION AND EQUIPMENT
CREW ESCAPE SYSTEM
EJECTION PANEL SEVERENCE SYSTEM

FIGURE III-9



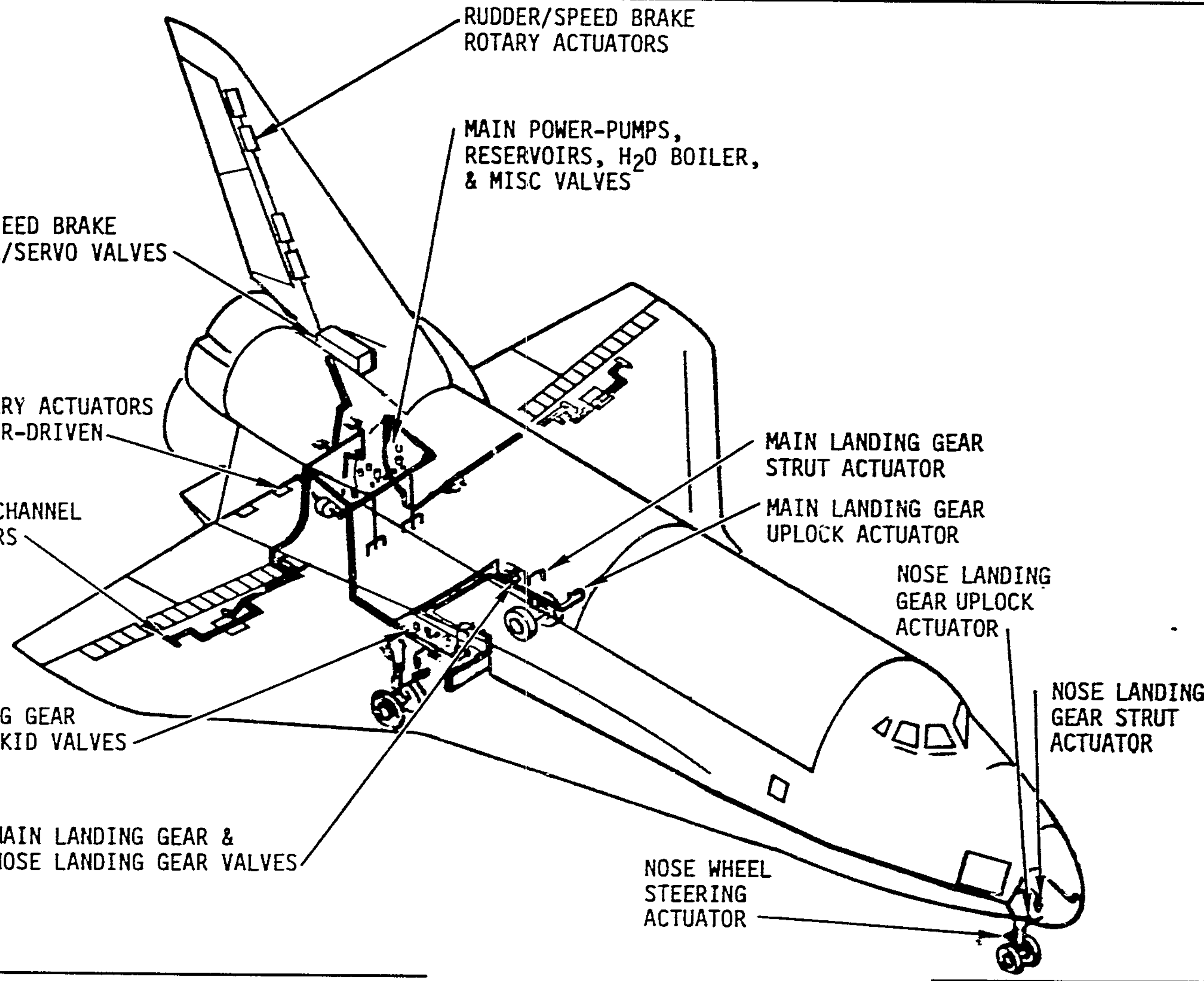
PRIMARY EMERGENCY GROUND EGRESS

FIGURE III-10



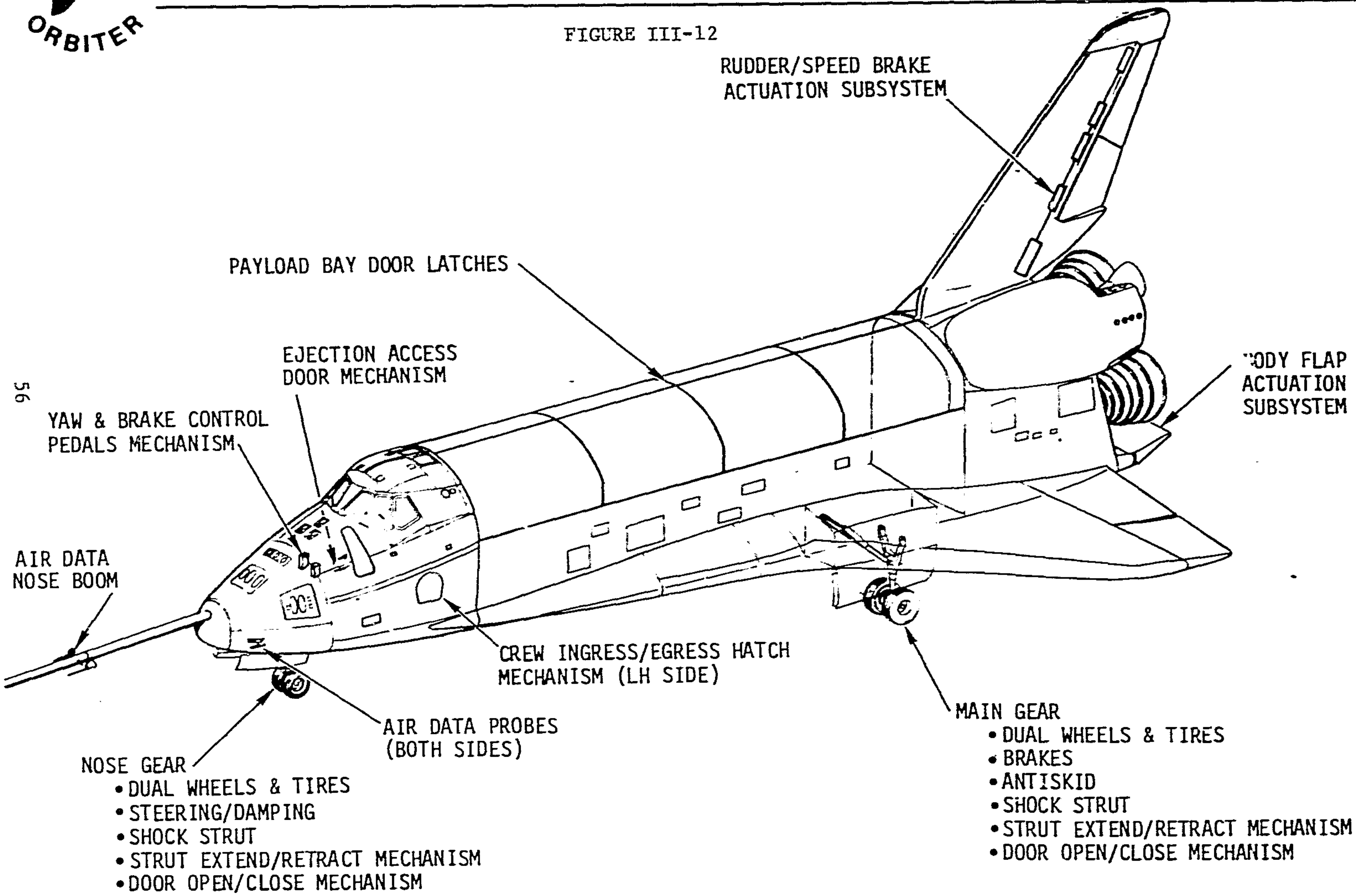
DCR OV 101 ALT
HYDRAULIC SUBSYSTEM

FIGURE III-11



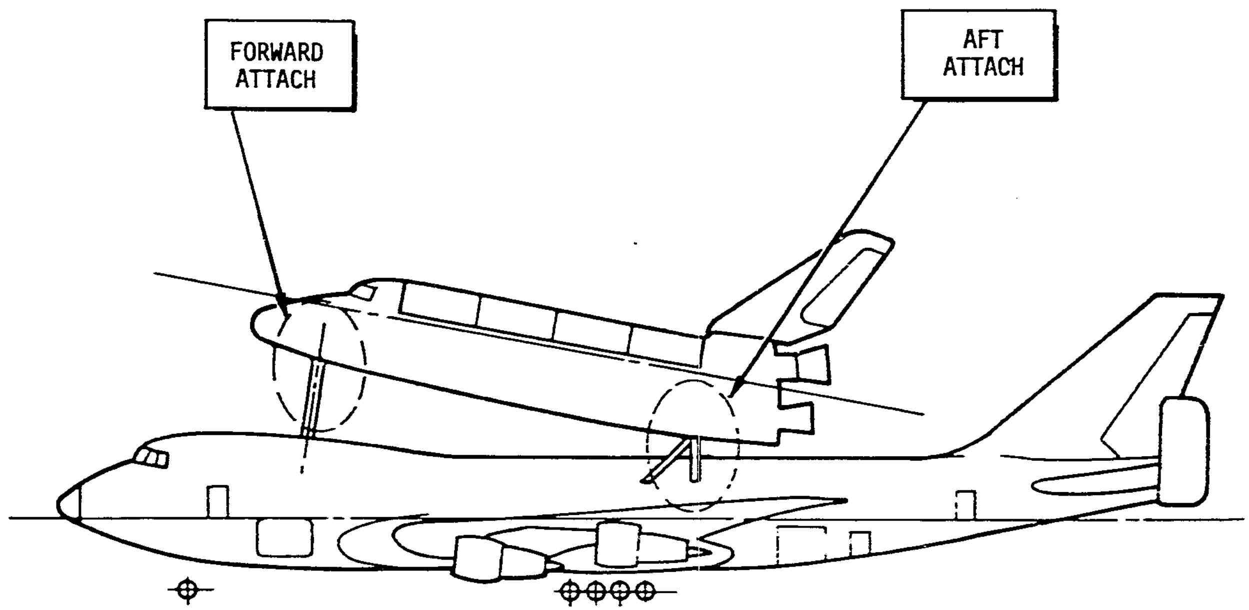
DCR OV 101 ALT
MECHANICAL/ACTUATION SYSTEMS

FIGURE III-12



DCR OV 101 ALT
MECHANICAL SEPARATION SYSTEM

FIGURE III-13



IV. SHUTTLE CARRIER AIRCRAFT, 747

A. Introduction

The basic 747 Model 123 aircraft was qualified in 1970 by FAA certification. Rockwell, the prime contractor, procured the services of the 747 manufacturer, The Boeing Company, to modify the vehicle to meet Shuttle requirements as an ALT carrier aircraft and as a ferry vehicle. Flight tests initiated on December 2, 1976 are currently being completed. Delivery to the DFRC site was made on January 14, 1977 in preparation for the first captive flight of the Orbiter set for February 18, 1977.

B. Observations

1. ALT requirements/General and Specific.

The key technical requirements are in six areas: orbiter weights, stability and control, handling qualities, structures, environment and modification criteria. In addition, there are specifications for such things as the separation clearances after orbiter release, communications, and interfaces with ground facilities for mating purposes. Table IV-I provides a brief overview of the requirements of principal interest. The separation requirements are depicted in Figure IV-1 and the communications in Figure IV-2.

2. Airplane Modifications

The modifications required to meet the ALT and Ferry requirements fall into two categories: (1) permanent modifications and (2) removable modifications. These modifications are shown in Figures IV-3 and IV-4. Permanent modifications are those made to the basic structure

and subsystems that remain with the airplane. These modifications certifiable by the FAA and are of a nature that the airplane configuration could be type-certificated for commercial use if required. The airplane presently is designed as a "Public Aircraft" and does not require FAA certification. Removable modifications have been made to the structure and subsystems in what is commonly called "kit" form. Design definition and verification of these modifications were obtained through a comprehensive analytical and test program which is described later on.

3. Design Verification

This work was accomplished through (a) utilization of the extensive commercial airplane data base available, (b) analysis wherever possible, and (c) the extensive use of wind-tunnel testing to support analyses. For those permanently installed modifications, FAA criteria and participation were used. Because the program is basing its needs on flight-proven concepts and qualified hardware components there was no developmental hardware, no qualification tests, and the final verification was accomplished at the system-level.

Qualification tests on orbiter interfacing hardware and government furnished equipment (GFE) were performed where required based on the use of common aircraft and shuttle orbiter designs and qualified hardware.

The wind tunnel testing was accomplished in the following phases: (1) Configuration Development Tests to define or refine the external geometry of the modifications, (2) Design Verification tests to verify that the design of the modifications and the mated

SCA/Orbiter configurations will be satisfactory for the performance of the ALT missions, and (3) Design Data tests to provide data required for detail design analysis of flight characteristics, performance, control capability, airloads, and flutter boundaries. The tests were planned to obtain data for the SCA alone, and for the mated configuration for ALT flights. Air launch aerodynamics data were obtained from a combination of SCA-alone data and proximity effects data. A total of 3470 occupancy-hours of wind tunnel testing was completed using models ranging from 0.03-scale to 0.046-scale for high and low speed work respectively.

Aerodynamic characteristics were developed for those 747 and the mated configurations pertinent to the ALT program. These characteristics formed the basis of the performance analysis, determination of flying qualities which included detailed pilot simulation studies, and evaluation of failure cases. Analyses were conducted to determine recommendations for the optimum launch sequence.

Stability and control analyses were also conducted using the basic aerodynamic characteristics. Primary and automatic flight control system detail design requirements were defined. Flying qualities were determined both analytically and by piloted simulation. Manual and autopilot performances under normal and failure conditions were verified by 1200 hours of simulation usage.

Flutter analyses were accomplished to verify that the 747 final design is essentially flutter free up to 1.2 V_D which is equivalent to 1.44 times the dynamic pressure. V_D is the Design Maximum Velocity, indicated airspeed in knots. Wind tunnel tests indicate a minimum

margin of about 2.0 V_D. The mated flutter analysis work should be concluded in January 1977 and the verification work on coupled modes should be finished prior to the first mated flight in February.

The 747 structural design loads were developed based on the FAA FAR 25 requirements "Airworthiness Standards, Transport Category," except as modified to allow safe and efficient operation of the basic airplane during orbiter ALT flights.

Systems tests consisted mainly of the vehicle/system functional checkout and acceptance tests, major ground tests, and flight tests. Vehicle/system functional checkout and acceptance tests verified form and fit for all removable structure as well as subsystem end-to-end operability and performance. The major ground tests performed included a ground vibration test or modal survey and an electromagnetic compatibility test. Flight tests currently in progress will complete the verification testing prior to mating with the orbiter for ALT and will demonstrate airworthiness of the 747. Principal test objectives include checks on flutter, stability and control in both the manual and the automatic flight control modes, performance, loads and buffet .

4, Major Areas of Concern

To assure safety of flight and successful ALT missions the following items are to be followed in detail.

The buffet effect of the orbiter (tailcone-off) on the aft sections of the 747 may limit the crew capability because of excessive 747 cockpit vibration. Tailcone-on flight (the greatest number) do not present a concern due to buffet. The 747 crew must have absolute control over the aerodynamic controls and displays at the time of separation of the orbiter

from the 747 to assure proper and safe operation. Current calculations, based on available data, indicate that the 747 structure fatigue life is about 50 hours of mated flight (Tailcone-off) particularly in aft sections of the 747. Flying qualitites are expected to be somewhat degraded due to the mated conditions.

To meet these concerns a number of steps are being taken, including:

a. Instrumentation is installed to monitor loads and stresses.

b. Critical structure is inspectable and relatively short flights are to be followed by inspections.

c. Incremental flight test program allows gradual expansion of the flight envelope and permits a greater understanding of the adequacy of the structures after each flight.

d. Current tailcone-off ALT flight plans call for less than 10 hours of flight time, depending upon the impact of initial tests and actual flights.

e. Full-scale buffet can be evaluated at lift-off and the 747/orbiter landed immediately on the dry lake bed if buffet is excessive.

5. Special Areas of Certification

This deals with the details of the separation panel, communication interface unit, S-band transceiver/antennas and the load measurement system as well as the government furnished equipment. The government furnished equipment is discussed briefly here, while those interfaces with the orbiter are discussed under the orbiter section of this report. GFE (government furnished equipment) includes the 747 crew bailout or escape system, L-Band telemetry equipment, C-band beacon, UHF radio and the separation camera.

The crew escape system relates directly to the 747 crew safety during the ALT program. The design concept was discussed and accepted in the Panel's previous Annual Report and only the pertinent areas are mentioned here along with the verification results to date.

The basic system must provide depressurization of the 747 crew areas and evacuation route within 5 seconds to preclude any adverse impact on crew movement or om the escape-chute system. At the same time this is happening an opening is cut in the lower fuselage and an aerodynamic spoiler is extended. The escape system uses standard, developed, Air Force hardware. All pyrotechnic components have been through military qualification testing. The verification method is as shown in Table IV-II and the certification plan as shown in Table IV-III.

TABLE IV-I

OVERVIEW OF REQUIREMENTS (747 Aircraft)

Orbiter Weights	performance requirement	150,000 lb to 170,000 lb
	launch altitude baseline	152,000 lb
	structural design	192,000 lb
Structures	commercial airplane design loads criteria per FAR #25 - minimal deviations only for maneuver load factor for ALT of 2.0 - ultimate crash load factors of forward 6.0 aft 1.5 side 1.5 down 3.75 up 1.5 - fatigue life based on Orbiter tailcone on mated flights. Fatigue to allow 55 ALT Flights and 265 ferry flights. - fail-safe design except 747 nose gear and orbiter support structure	
Handling Qualities	When Orbiter is mated, the carrier aircraft is: - safe operation with all stability augmentation failed - controllable during take-off and landing in 15 kt x-wind - controllable with one orbiter rudder hardover - controllable with critical 747 engine failed.	

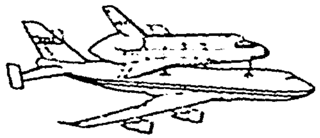


TABLE IV-II

CERTIFICATION INDEX

for the 747 Escape System

ITEM	COMPONENT TYPE			NO. OF TESTS	ENVIRONMENT			
	STRUCTURAL	EXPLOSIVE FUNCTIONAL	NON-EXPLOSIVE FUNCTIONAL		TEMPERATURE	VIBRATION	SHOCK	LOAD
INITIATION ASSEMBLY		X		—	S	S	S	S
SAFETY COVER			X	—	A	A	A	A
SAFETY HANDLE		X		—	S	S	S	S
TIME DELAY (3.00)		X		—	S	S	S	S
TIME DELAY (0.300)		X		—	S	S	S	S
WINDOW BURSTER ASSEMBLY		X		15	T	A	A	A
EGRESS PORT CUTTER		X		6	T	A	A	A
RIB CUTTING S/A		X		19	T	A	A	A
STRINGER CUTTING S/A		X		19	T	A	A	A
EXPLOSIVE VALVE		X		11	S	S	S	A/T
ACCUMULATOR			X	11	S	S	S	A/T
BOX, TAMPER PROOF			X	—	A	A	A	A
SPOILER ASSEMBLY	X		X	11	T	T/B	T/B	T/B
LINEAR ACTUATOR			X	4 x 11	T	T	T	T
ESCAPE TUBE INSTL			X	—	—	B/D	B/D	B/D
747 STRUCTURE	X			—	—	D/B	D/B	D/B
GUIDE RAILS			X	—	--	D	D	D

CERT CODE:
T = TEST
S = SIMILAR
A = ANALYSIS
B = ANALYSIS
D = ANALYSIS

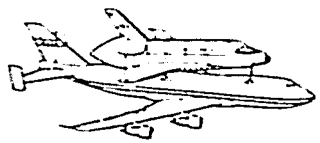
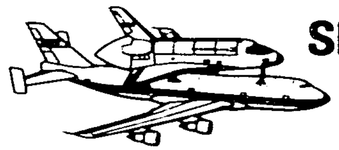


TABLE IV-III

VERIFICATION METHOD
for the 747 Escape System

	MIL QUAL TEST	ANALYSIS	TEST
• PYROTECHNIC COMPONENTS	T/McS *		T/McS
• SPOILER/THRUSTER ASSEMBLY		T/McS	T/McS
• WINDOW BURSTERS		T/McS	T/McS
• ESCAPE HATCH CUTTER		T/McS	T/McS
• AIRCRAFT FLOOR BEAM MODS		DFRC	
• ESCAPE TUBE INSTALLATION		DFRC	
• GUIDE RAILS		DFRC	
• DEPRESSURIZATION CYCLE		JSC/BOEING	
• AIRCRAFT STRUCTURAL INTEGRITY		BOEING	

* Teledyne McCormack Self Company



SEPARATION CLEARANCE DESIGN REQUIREMENTS AND GOAL

FIGURE IV-1

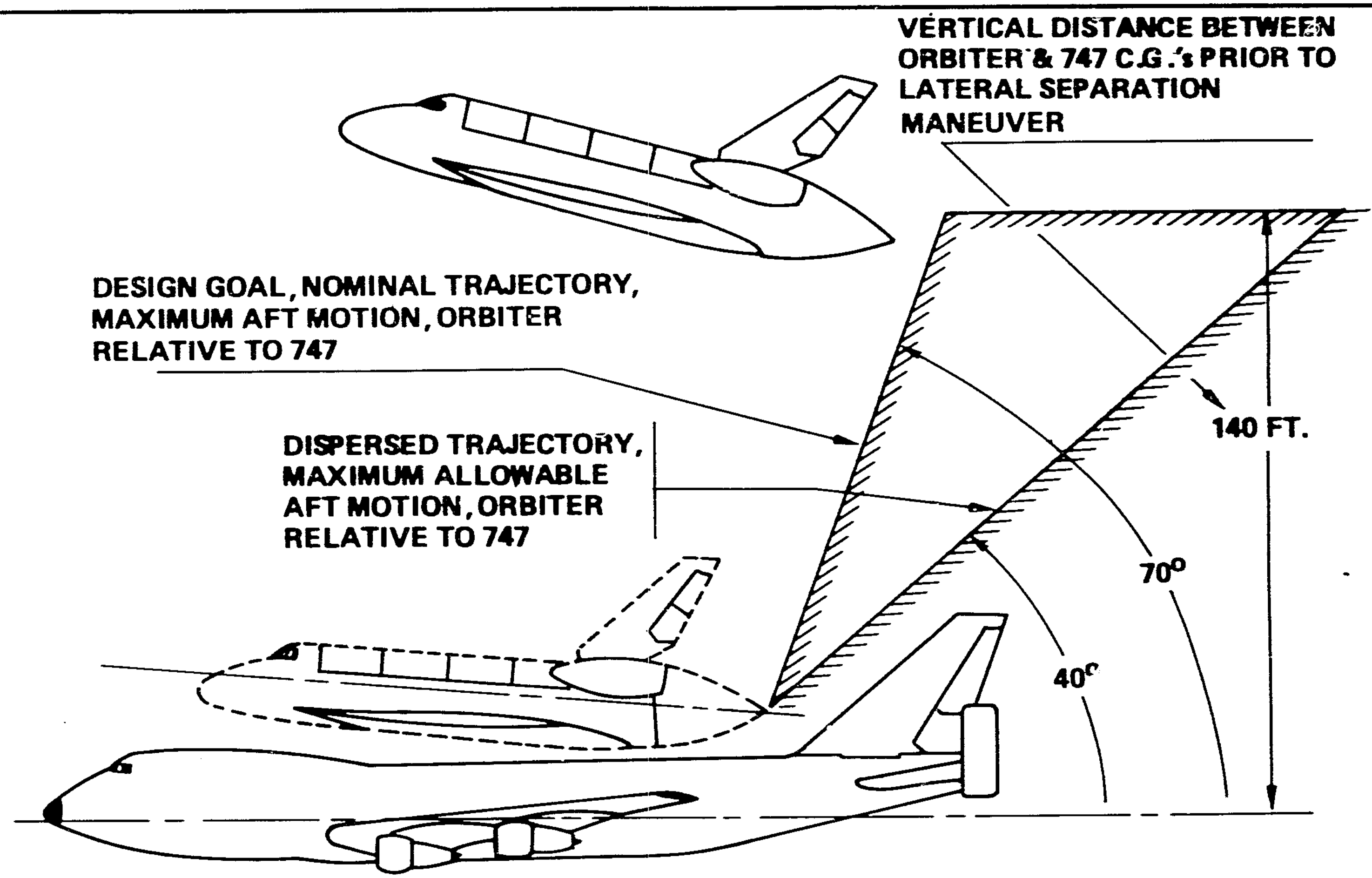
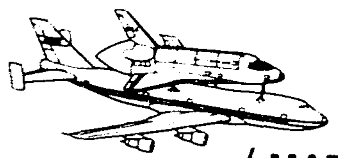


FIGURE IV-2A



AIR-TO-AIR & GROUND COMMUNICATIONS INTERFACES
(MATED 747 SCA TESTING – POWERED/MANNED ORBITER)

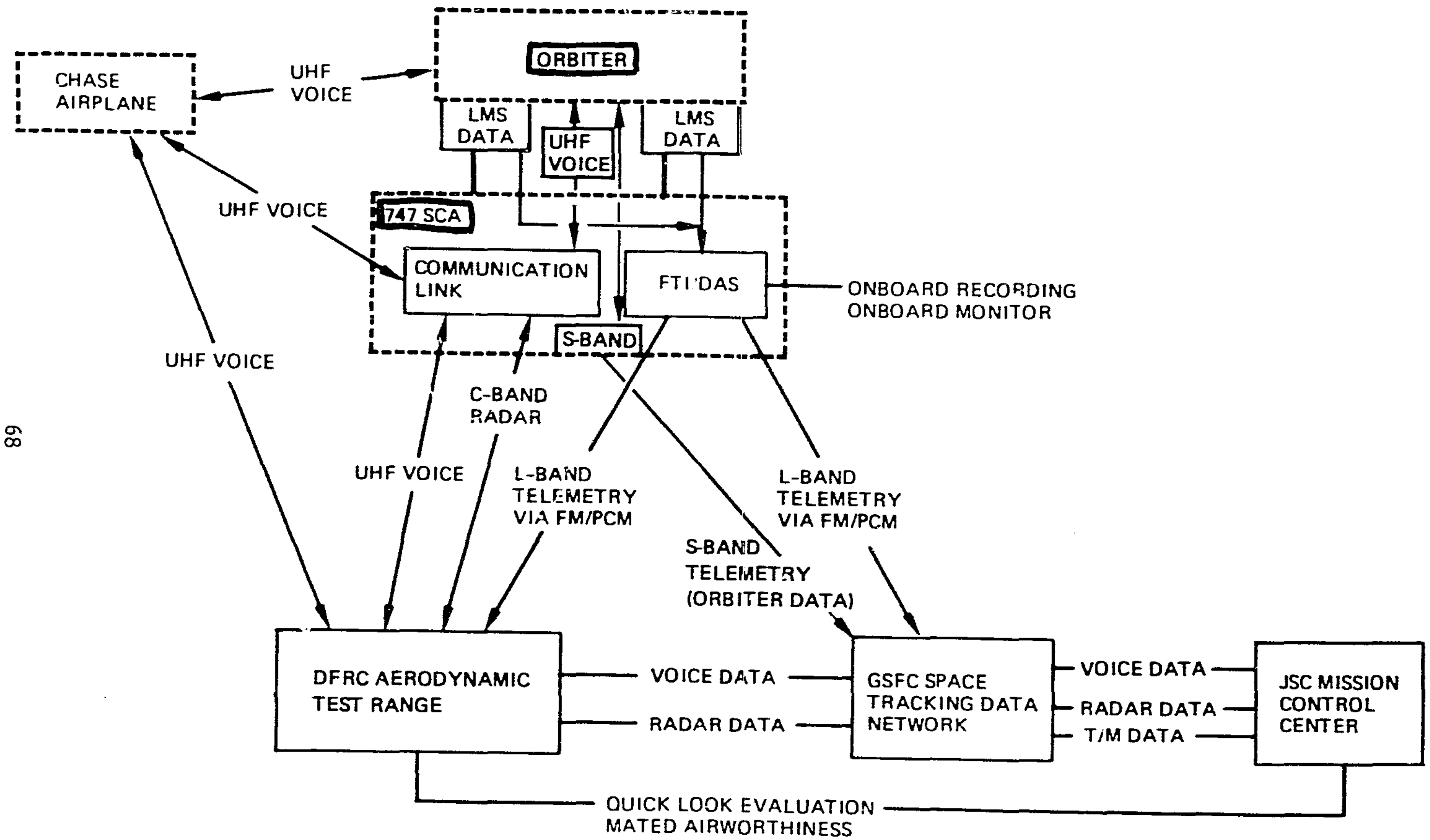
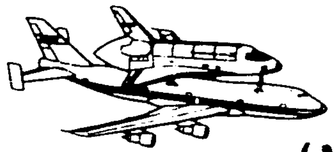
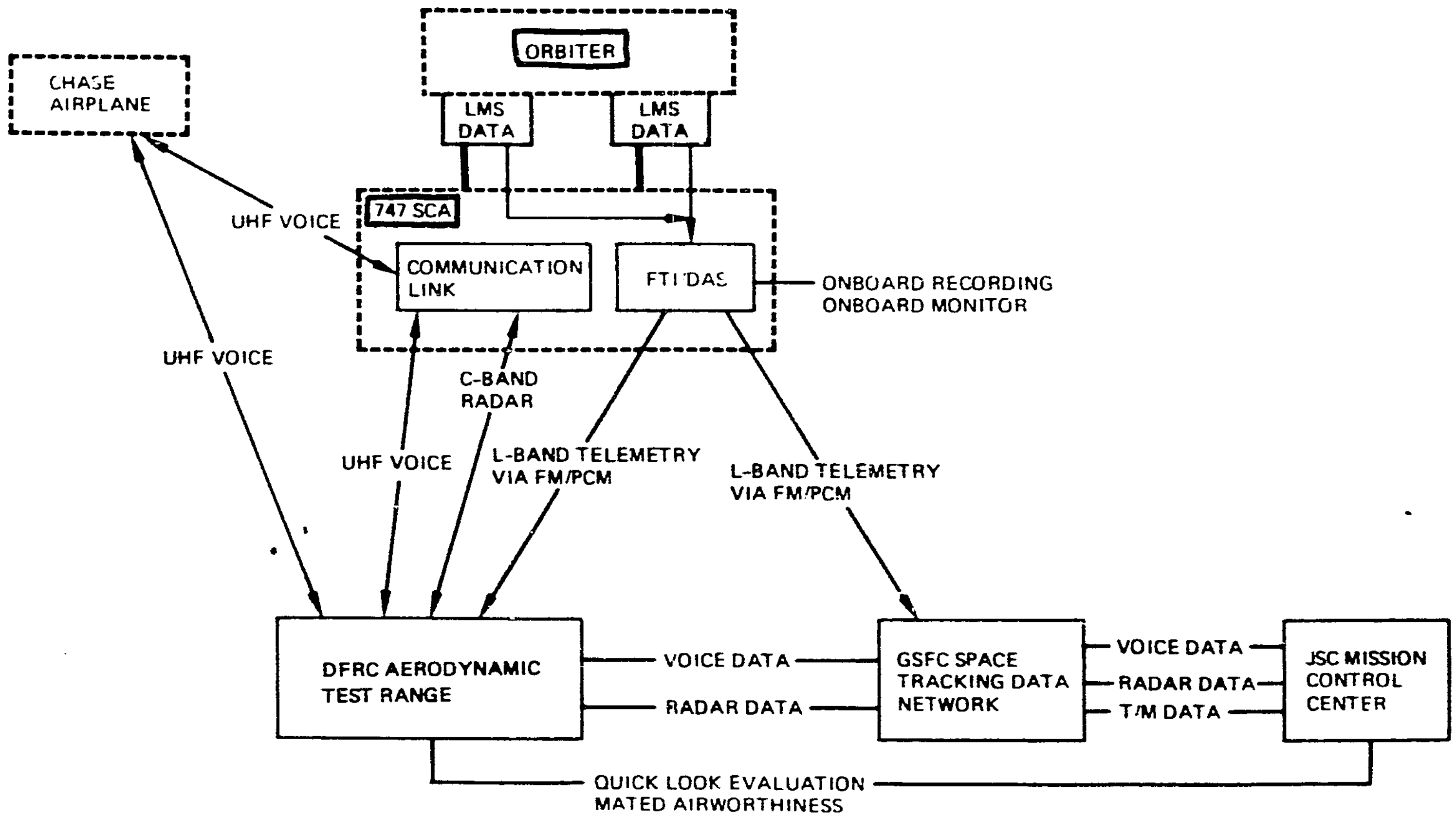


FIGURE IV-2B



AIR-TO-AIR & GROUND COMMUNICATIONS INTERFACES

(MATED 747 SCA TESTING — UNPOWERED ORBITER)



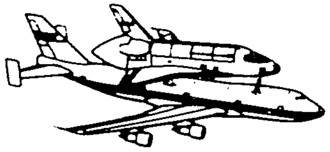
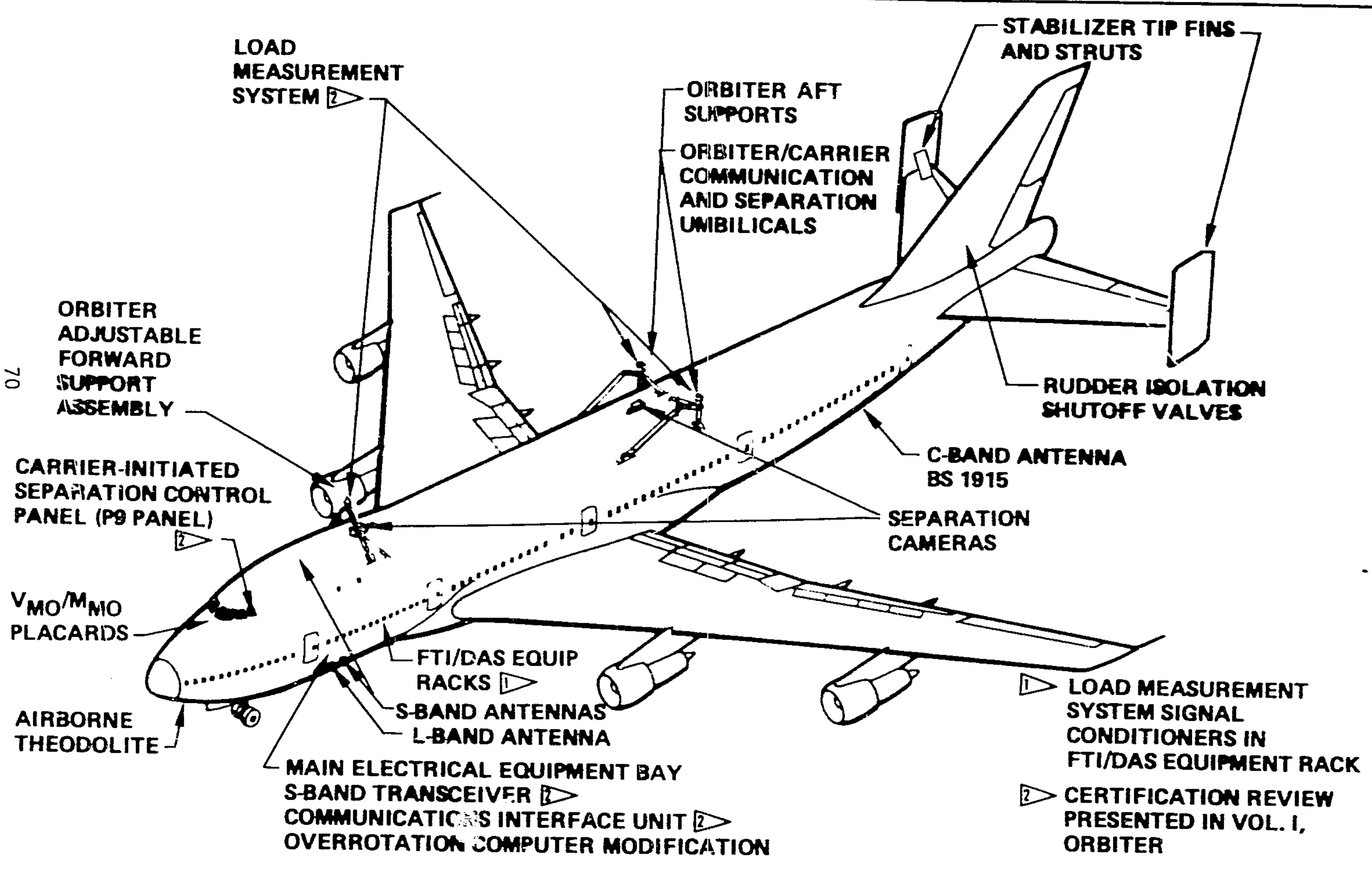


FIGURE IV-3

REMOVABLE AIRPLANE MODIFICATIONS



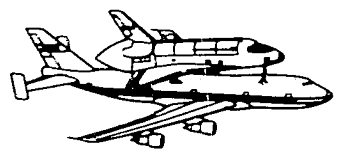
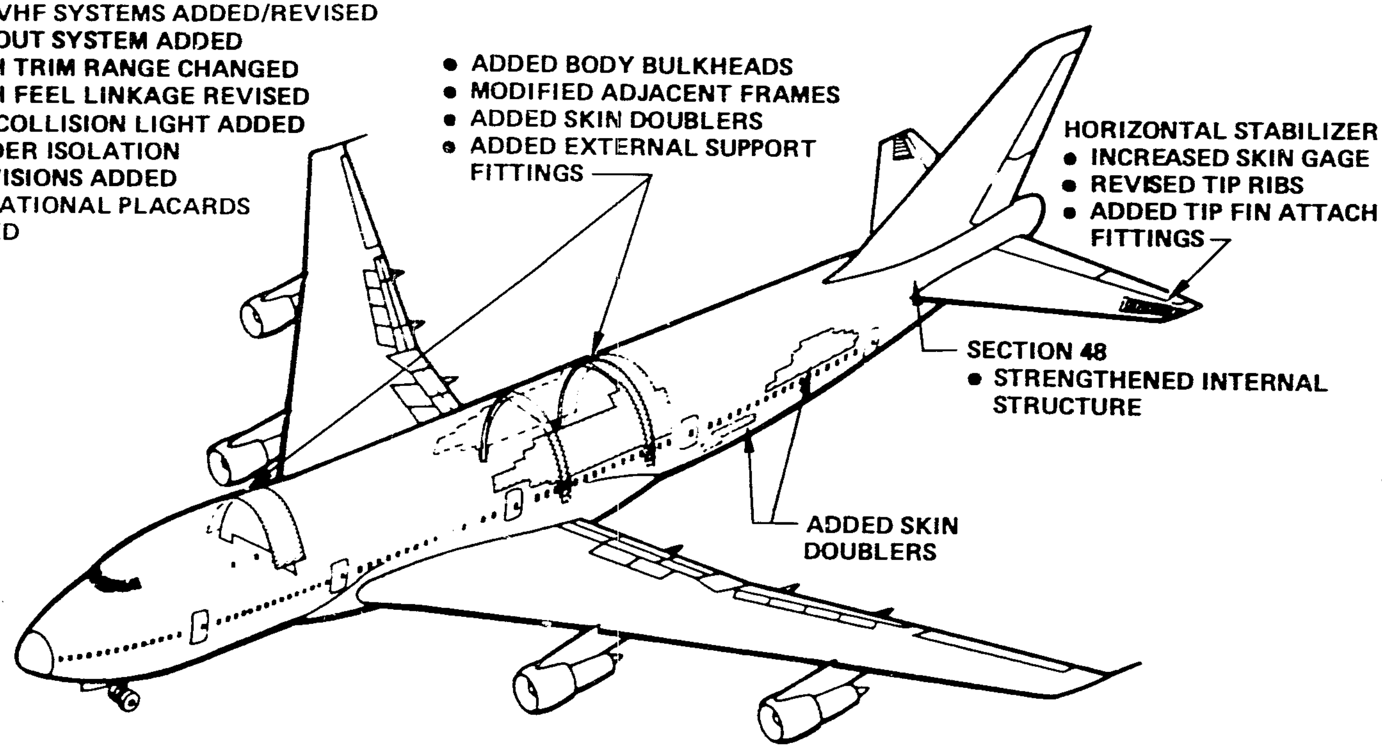


FIGURE IV-4

PERMANENT AIRPLANE MODIFICATIONS

AIRPLANE SYSTEMS REVISIONS
- ENGINES UPGRADED TO JT9D-7AH
- ENVIRONMENTAL CONTROL MODS
- CIRCUIT BREAKERS & SWITCHES ADDED
- SIDESLIP SYSTEM ADDED
- UHF/VHF SYSTEMS ADDED/REVISED
- BAILOUT SYSTEM ADDED
- PITCH TRIM RANGE CHANGED
- PITCH FEEL LINKAGE REVISED
- ANTICOLLISION LIGHT ADDED
- RUDDER ISOLATION PROVISIONS ADDED
- OPERATIONAL PLACARDS ADDED



V. ALT OPERATIONS

A. Introduction

Much of this area has been covered in other sections of this report. ALT planning, procedural and implementing documents have been discussed in Section II. This section covers only those activities conducted at the Houston Mission Control Center and at DFRC which support the ALT missions. This area comes under discussion again in Section IX, "Configuration Management." Thus, this section will be very brief.

B. Observations

The ALT functional organization is shown schematically in Figure V-1.

1. ALT Scheduling and Status Monitoring

This area as required for ALT is to be performed under a manual system. Schedules will be maintained for three levels, as well as any supplemental level deemed necessary.

The first is the ALT program schedule which encompasses the entire ALT program with sufficient detail to show each flight, each ground turnaround, each major ground test period, and each NASA controlled and ALT planning milestone.

The ALT Planning Milestones that control ALT scheduling and status monitoring system is defined in APD No. 121, dated October 19, 1976. These milestones start with the 747 on-dock at DFRC on 1/14/77 and go through completion of free-flights with tailcone off on 1/13/78. These dozens of milestones actually cover from 11/1/76 through 3/17/78.

The integrated ALT work schedule then plans for a 14 working day duration (72 hours/11 days) including all ALT milestones within those 14 working days, and all element interaction and external interface milestones derived from Element Work Schedules. This integrated schedule is to be published each working day. The third level of scheduling provided the Element Work Schedule which support the Integrated Schedule. Finally, a recovery schedule is established when necessary because of difficulties in meeting the next ALT Planning Milestone in the Integrated ALT Work Schedule or the ALT Program Schedule does not provide accurate schedule information.

2. ALT Management

The management structure includes the Manager DFRC ALT operations, Active Orbiter Flight Director, and the Orbiter Ground Operations Manager.

The documents that deal directly with the day-to-day operations both at JSC and at DFRC in support of the ALT mission include:

MI-108	Customer and Contractor C/O Support functions
112	Operational Support and Documentation System
113	ALT Ground Operations Scheduling Activities (ISSUED)
118	ALT Control Room Operations
120	ALT Support Coordination (ISSUED)
304	Performing Flight Readiness Review

Only about one-sixth of these have been issued at the time of this writing.

3. Mission Rules

As in all missions, a set of mission rules are established which specify what is to be done (the decisions are pre-selected) for a specific set of events which are off-nominal. These have been thoroughly analyzed and tested both on paper and in simulations to assure known results. These mission rules are provided for each phase of the flight, i.e., mated inert taxi tests, mated prior to take-off, mated takeoff, after takeoff, inflight, and so on to final position after landing. Typical of such rules for that period of flight immediately after takeoff would include:

- If the landing gear doors are found to be open or gear will not retract the decision is to abort the mission.

- If there is a single blown tire on the 747 an inspection is to be made by the proper chase plane to ascertain the exact condition and if no other damage is descernable either by chase or by displays onboard then the mission may continue as a nominal mission.

Such rules are developed for each critical area. For instance the hydraulic systems may have mission rules which establish five basic decisions which can be effected depending upon how many hydraulic systems are lost on the 747. These five decisions are: emergency jettison of the orbiter 101; abondanment of the 747; abort the mission and return to the base; continue the flight in a reduced environment (minimize stresses); or continue the flight as scheduled. Thus with the loss of one,two or

three 747 hydraulic system the decision would be to abort the mission and return to the base, while with the loss of all four systems the decision would be to abandon the 747.

4. Contingencies Operations

The thoroughness of the planning for ALT flights is demonstrated by the contingency operations plans whose objectives are manifold to assure that everything that can be done will be done. The objectives in chronological order if you will are: preserve life/minimize injuries; preserve vehicles and property; secure the contingency landing site; secure all possible information relating to the incident; and assure administrative actions are taken as required including the appointment of an appropriate review board for investigations.

There are two categories to deal with: (1) abnormal test vehicle condition (OV-101, 747, or both) which has produced or is resulting in substantial damage to the test vehicles and/or injury to personnel, (2) Accident or incident involving damage to facilities or equipment other than the test vehicles. These are covered in the ALT Contingency Plan and by appropriate NASA Agency documents, particularly NHB 1700.1 and NMI 8631.1B.

5. Other Areas of Operations

The post flight data reduction analysis and reporting system includes the DFRC "quick-look" program, The Boeing Company program which is to be utilized only through the captive inert flights, all of which is to provide summary reports to the ALT manager and his people within 24 hours.

Such reports will contain such things as the objectives accomplished, the crews comments, engineering comments, and a thorough problem assessment.

Emergency jettison of the inert orbiter, if it were ever to be necessary, has been examined to assure that the limits of such actions are known. Wiring and controls are provided so that the 747 crew can initiate the jettison of the orbiter if such a contingency should occur. Analyses and simulations have been conducted to assess the procedures, jettison capability, and the best orbiter elevon fixed position. NASA/DFRC pilots, as well as others, have participated in the "man-in-the-loop" simulations. As a result of these activities the following results are known so far:

(1) Successful emergency jettison is very sensitive to the position of the orbiter's elevon, and that increased negative or up elevon improves clearance for inert flights. Based on the best available data at this time it appears that nominal separation requires at least a zero-degree elevon to preclude collision. Thus for the ALT inert flights the -1 degree up-elevon was selected to assure a safe emergency jettison for nominal conditions and a 50% of uncertainty range.

(2) The airspeed range over which a successful emergency jettison can be performed range from 200 KnotsCAS to the 747's V_D/M_D limit speed. Additionaly, 747 pushover is required at lower airspeeds to provide positive relative normal acceleration.

(3) The jettison altitude is not significantly constrained, except

that an altitude loss of 2000 to 3000 feet may occur prior to 747 recovery after the release. The jettison time required is about 6 seconds.

(4) The steps to be taken upon the declaration of an emergency situation requiring orbiter jettison go something like this:

Left Seat Pilot	Right Seat Pilot
"Chop" the throttles	Arm the jettison system on panel P9
Deploy the speedbrakes	
Perform a pushover @ 0.3g	As the 747 engines approach idle initiate jettison through Panel P9
Maintain the pushover for the proper time (6 seconds)	

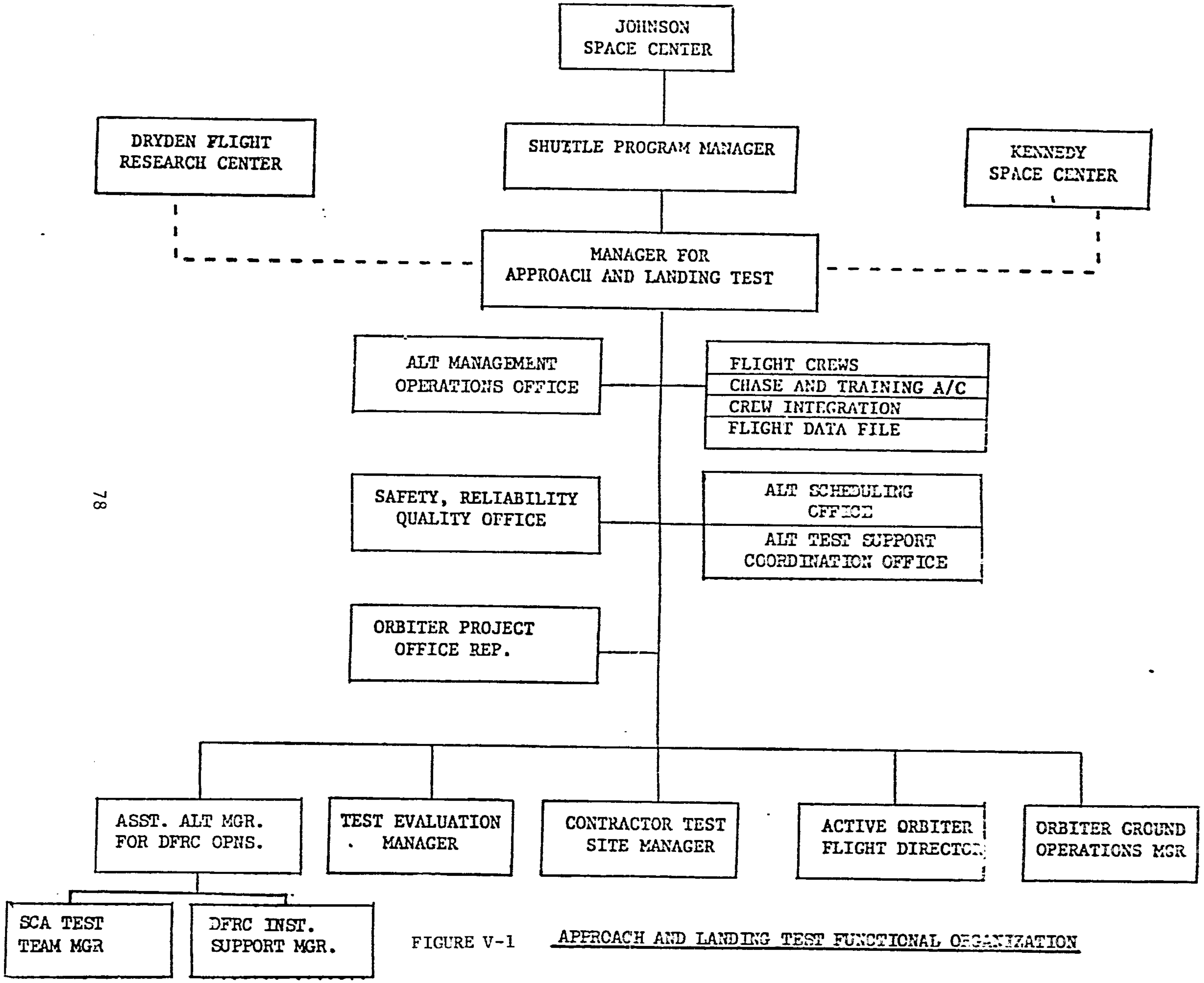


FIGURE V-1 APPROACH AND LANDING TEST FUNCTIONAL ORGANIZATION

VI. GROUND FACILITIES

A. Introduction

The Shuttle Master Verification Plan states that Ground Support Equipment (GSE) must undergo formal certification by test or analysis where the expected environmental conditions, operational constraints, or the significance of a hardware failure indicate it is necessary to assure an appropriate level of confidence in the GSE beyond that provided by acceptance testing. The responsible GSE design group identified the ground support equipment and the appropriate test/analysis plan, procedures and implementation initiated. They identified for Orbiter 101 five models (sets) of quick disconnect filter assemblies for the APU, NH_3 servicing, ground cooling, freon servicing and waste disposal, and PRSD/FCP. All of these have been certified.

B. Observations

1. Key Orbiter GSE Management Documentation

There are a number of directives and implementation documents which guide the development and qualification of the ground support equipment. They key items are listed in Table VI-I.

A key to providing GSE and facilities on-time and in adequate configuration to meet the ALT/OFT/Operational needs is strict Configuration Management (see Section IX).

2. Safety Requirements on GSE

From the viewpoint of safety of operation, ground equipment is considered in the same light as flight equipment. To achieve this a number of steps are taken:

a. A Safety Critical Item List (CIL) is established as described in NASA NHB 5300.4 (ID-1). The policy requires hazard analyses to identify a potential hazard and their resolution as well as the safety requirement verification which calls for test-to-safety margins.

b. Each end item is reviewed by NASA and Contractor through formal design reviews which utilize the RID system to assure that issues are identified and formally resolved.

c. A functional end item verification is performed at the completion of the end item fabrication. When that is completed an integrated schematic verification is also made.

d. Other steps in the certification process include the station set validation of the GSE-to-Vehicle interface, the update of configuration acceptance readiness reviews, and the Flight Readiness Review.

The current plan for GSE to support the ALT program calls for use of Station Set 16 and transfer of much of the GSE used with Orbiter 101 at Palmdale ("Caravan GSE").

3. Facilities

The team reviewed the Approach and Landing Complex and flight operations support facilities at DFRC and JSC.

a. DFRC

The basic items supplied to DFRC by KSC for use in the ALT include facilities, communications systems and the mate/demate device, plus certain government furnished equipment. In addition KSC supplied

the requirements for fixed facilities at DFRC as to the tow-way, shuttle hanger, mate/demate device foundation, facility AC power, emergency power, fire protection and hazardous storage areas, hoists, microwave tower and other items. The ALT complex facilities were accepted from the contractor on August 16, 1976 after acceptable completion of all testing. Open items still exist, but are to be closed during the January/February time period for support of the ALT missions as required.

The Mate/Demate Device, since it is unique to NASA experience, is probably of interest to the reader and should be described briefly.

(1) It has a lifting capacity of 225,000 pounds.

(2) Its structure is designed for maximum winds of 125 mph at the 30 foot level.

(3) Lateral controls will hold Orbiter steady in a 12 knot wind.

(4) There is positive lifting control by three 50-ton hydrosets.

(5) There is a deluge system for spills of hazardous materials.

The communications arrangement for working at DFRC includes an operational intercommunications system, a radio frequency communications system, and a paging/area warning system. This covers the local area and also supplements the DFRC-to-Palmdale 2-wire system with an 11-channel, 4-wire system.

The 747 equipment for maintenance and flight support includes

standard 747 ground support equipment (GSE) and the Flight Monitor Room and Telemetry Processing Area at DFRC. It is in effect a mission control room for the 747 up to the interface with the Orbiter. It also supplies the direct interface communications between DFRC and JSC and its mission control center. The communications at DFRC include:

(1) Air to ground.

(2) Local ground data flow.

(3) Tracking data system.

(4) Telemetry monitor system.

(5) Chase Plane/Trailer/Long Range Optics Television system.

While at DFRC the 747/Orbiter will undergo a Mated Ground Vibration Test (MGVT). The details of this test have not been reviewed by the Panel.

b. JSC

Flight Operations Support has specific areas of responsibility, as shown in Figure VI-1. The ALT Mission Control Center has been located on the third floor, Building #30 at JSC. The following functions are contemplated: telemetry processing, track processing, communications, television, with displays to cover all systems and follow all operations on a real-time basis with memory and data playback. The system capability is for an update rate of once per second and to process 1,330 parameters and record 125 events. It needs to be on time to support the February unmanned Orbiter mated flight and fully operational for the fully operational Orbiter in March.

c. Communications and Data System

The importance of this portion of the facilities to be applied to both the ALT and OFT programs cannot be overemphasized. In this area the orbiter is one of the key elements along with the ground segments of the communications and data system. The elements of the system are not all brought into operation at one time, rather they are phased into operation as they become required. Thus for the ALT program the requirements include the orbiter, DFRC, one STDN (Space Tracking and Data Network) site, GSFC and the Mission Control Center at JSC. The first three OFT flights as presently conceived do not require DFRC, but add the Launch and Landing requirements affecting KSC and MCC (mission Control Center) plus an additional ten (10) STDN sites. The remaining OFT 4-6 flights require the Tracking and Data Relay Satellite and its ground station added to that already used on OFT 1-3. The Orbiter itself adds capability in the same way, e.g., during ALT it uses modified S-band system, for OFT 1-3 it uses the S-Band PM and FM system, then going to the S-Band (PM and FM) plus Ku-Band system adding payload interface requirements as needed. The major development effort for the OFT MCC will start about the middle of FY 1978.

TABLE VI-I

Key Documents for GSE

I. Directives

A. Level II Specification, JSC 07700, Volume X "Flight and Ground Specification"

B. Space Shuttle Program Directive #19, "Ground Systems Support Equipment Design and Control System."

C. Space Shuttle Program Directive #71, "Ground Operations Panel"

D. Space Shuttle Ground Support Equipment Integration Plan, JSC 08110

II. Implementation

A. Orbiter GSE Management Plan

B. GSE requirements definition document (RDD)

C. Abbreviated item description sheet

D. GSE utilization List (GUL)

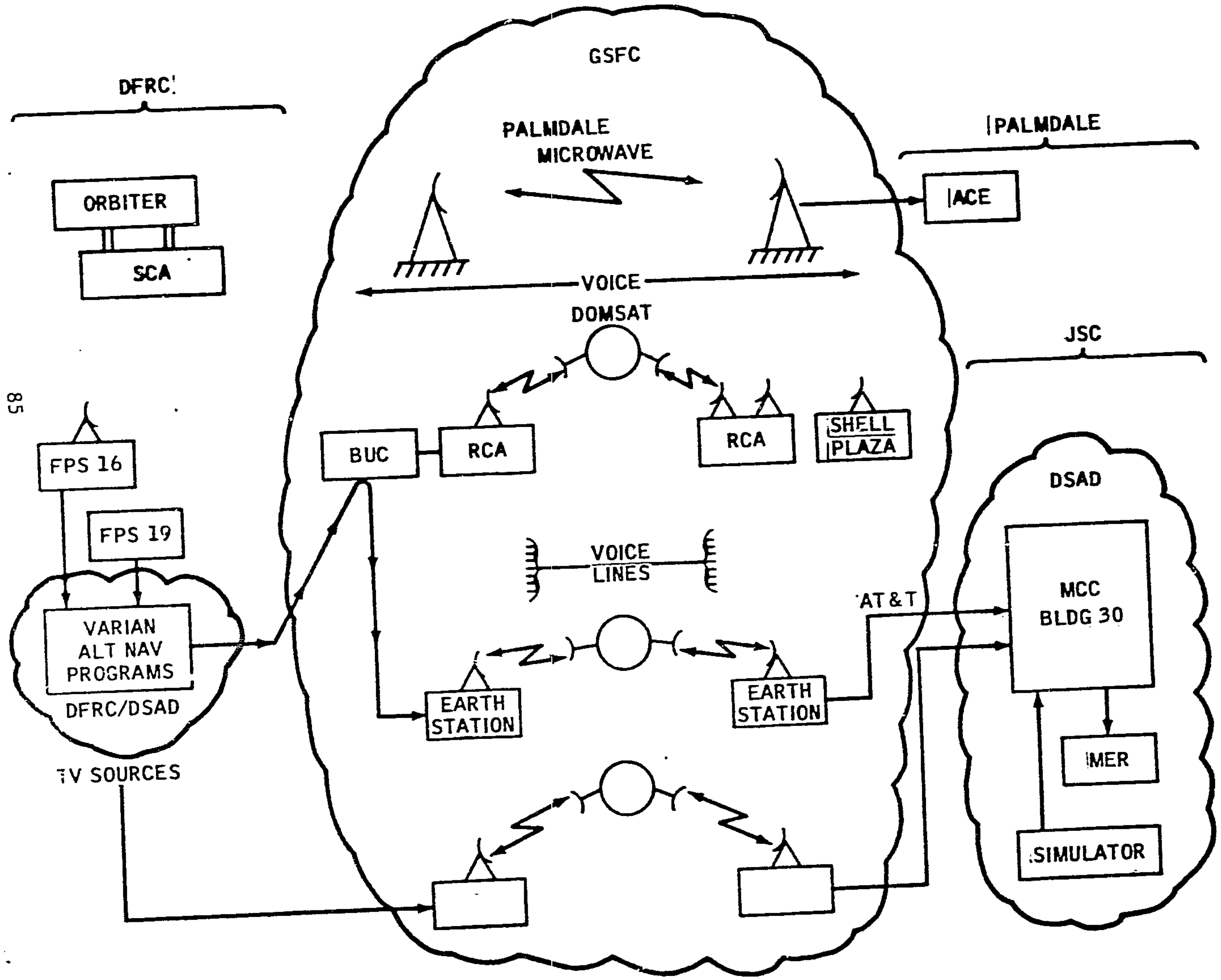
E. Station Set Specifications

F. GSE Design Requirements, SW-E-0002

FLIGHT OPERATIONS SUPPORT

AREAS OF RESPONSIBILITY

FIGURE VI-1



VII. TRAINING THE GROUND AND FLIGHT CREWS

A. Introduction

The Panel reviewed the experience, training and competence of personnel. As in reviewing past programs, the Panel has focused on skill retention and morale among the ground and manufacturing personnel as well as the degree of training received by the flight crews in the unique aspects of mission operations.

A review of training must consider that tight schedules historically seem to generate more human errors resulting in equipment failures and mission anomalies than one might expect from the design of the hardware and software themselves. Thus training must be designed with this in mind to minimize such problems.

B. Observations

The observations for this segment of the report are reported in Volume I of the Panel's report. They deal mainly with the flight crew training at this time, and apply to the Approach and Landing Test Program only.

Flight crew and flight controller training was covered to some degree in the Panel's last annual report. The current status of development of the simulators and trainers are:

1. The orbiter aeroflight simulator (OAS) for the Approach and Landing Test has been in use since November 1976. It can be tied into the Mission Control Center for integrated simulations. The Shuttle

mission simulator (SMS) to be used for the Orbital Flight Test Program and operational missions is expected to be in use in April 1978. The OAS motion base crew station is to be updated upon completion of the Approach and Landing Test program and will become an integral part of the SMS. The SMS will be tied in with the Mission Control Center for integrated simulations. The Shuttle Mission Simulator moving base and fixed base crew stations will initially provide forward flight deck training only. The fixed base crew station will be upgraded later on to provide full flight deck training capability by at least the third manned mission.

2. The part task simulators include (a) crew procedures evaluation simulator, (b) shuttle procedures simulator, (c) spacelab support module simulator, (d) the interim upper stage simulator, and (e) the single systems trainer which has only been conceptually defined at this time. The spacelab and upper stage units are not expected to be in use until the 1979-80 timeframe. The other two, "a" and "b", are now in use.

A directive has recently been issued (JSC SSPD #75) to ensure the establishment and effective formal configuration control of the 1-G trainers, neutral buoyancy trainers, training devices, and related trainer facilities. This will keep the configuration up-to-date and responsive to the most current requirements.

An area that will be exercised to assure the highest possible level of capability is that of post-test data reduction and analysis.

This is bound to be a problem in both ground test and checkout as well as in post-flight operations because the amount of material to be processed is so large. Procedures and how they are to be implemented as well as dry runs should help to keep this problem in hand.

The ALT ground team training has been going on concurrently with the work being performed at DFRC in readying the ground and flight hardware for the ALT flight. The ALT ground training plan was developed by KSC, since this area comes under their cognizance, and was issued as document K-SM-12.5.01. Personnel requiring specific training in certain skills have been recertified through a series of intensive courses which are 100% complete. Special areas such as those handling toxic fuels and requiring emergency egress procedures on the ground have been the subject of training and are 100% complete. To assure that the ALT turnaround schedules can be met the crews have been trained in each of the steps involved. There is of course no substitute for the "real thing" which will enhance the skills which the ground crews already have obtained.

The Shuttle Carrier Aircraft (747) Test Team (SCATT) is a mix of DFRC, Rockwell, Boeing and JSC personnel. They have participated in the 747 test program planning, they were involved in the windtunnel and post modification testing and are the Flight Control Room Monitors at DFRC. The SCATT members also participated in the mated ground vibration test program, the taxi tests and any other area that dealt with the flight of the 747. Through a series of detailed reviews

these skilled technicians and engineers covered such areas as: flight test requirements, real-time monitoring, the DFRC control room setup, 747 and orbiter operational limits, flight crew and training requirements, and the mated inert flight plans and contingency procedures.

The flight crew training has been detailed and intense over the past two years. The pilots and lfight engineers have gone through the American Airlines 747 ground training schools and simulators, FAA 747-type ratings, current American Airlines refresher courses at the ground school and the flight engineers school and simulators. An example of the flying experience brought to the ALT program:

PILOTS	Total Hours	747 Hours	747 Landings
	12,800	114	90
	6,100	51	73
	9,450	55	61
	9,575	4	5
	14,450	38	47
total	52,375	262	276

FLIGHT ENGINEERS	Total Hours	747 Hours
	1,025	115
	2,625	105
	3,250	8
	3,000	8

The "chase" pilots have also been heavily involved in training for the ALT flights. The Chase procedures have been established and briefly they are that Chase #2 and #3 are to take off before the mated 747/orbiter, while Chase #4 will takeoff after. Two additional planes, Chase #2A and #3A will relieve the #2 and #3 planes at a pre-determined point in the ALT mission. The Chase pilot training includes attendance at the Orbiter ground school at JSC, the 747 ground school at DFRC, having the chase pilots involved in all crew briefings given for the 747 and orbiter crews. A schematic of chase-plane positioning is shown in Figure VII-1

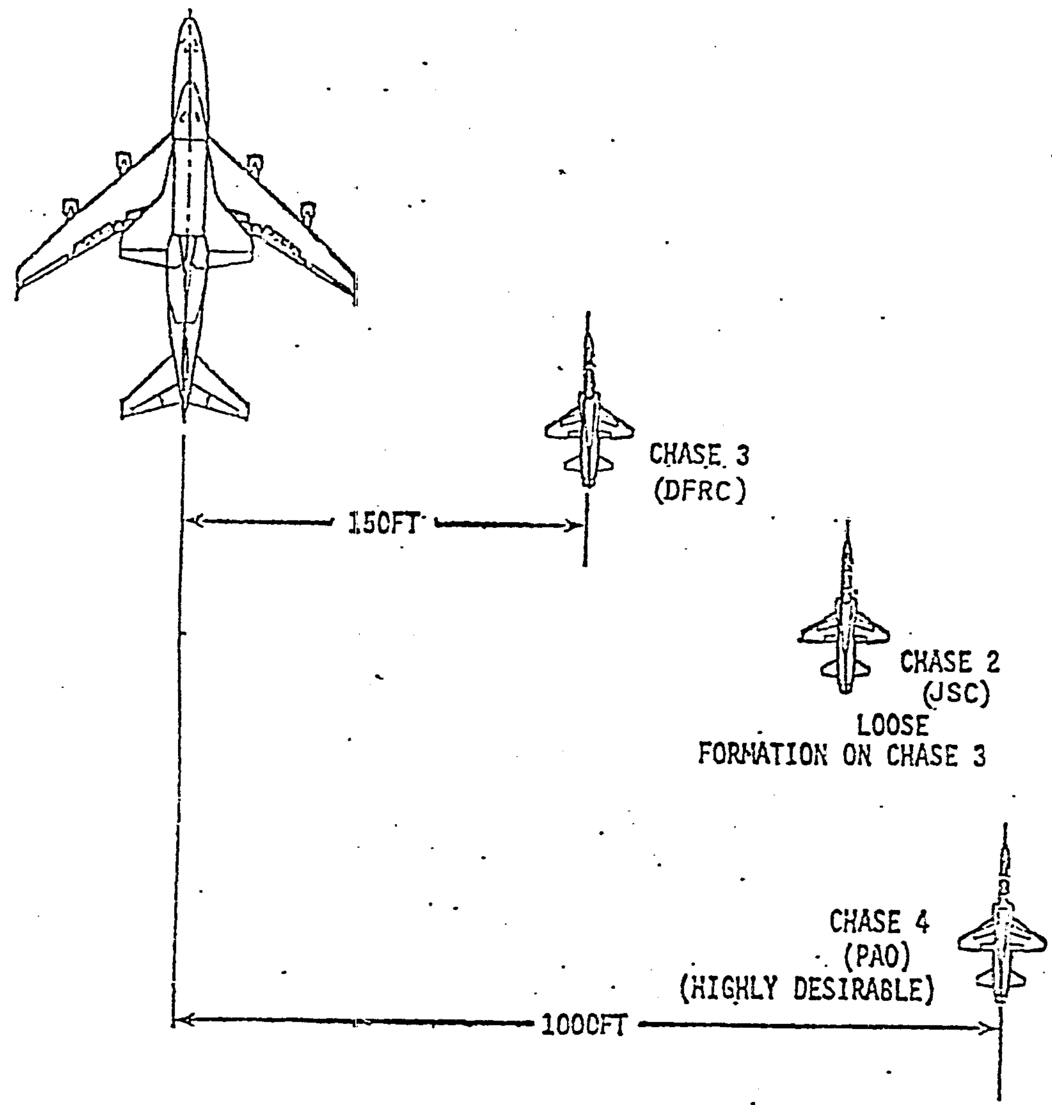


FIGURE VII-1 CHASE POSITIONING - CAPTIVE INERT FLIGHTS

VIII. SAFETY, RELIABILITY AND QUALITY ASSESSMENT

A. Introduction

These areas have been under constant scrutiny by the Panel as a whole as well as by a number of Panel Task Teams. Rather than plow through ground covered in varying degrees by other sections of this report, this section focuses on the mission safety assessment system as applied to the ALT project, and the system which screens or evaluates hazards and safety concerns as a part of the every day program operation.

This task team organized its review to answer the following questions:

1. Is there a reasonable basis of confidence, based on data presented, that the ALT mission safety assessment has been thorough and adequate, and supports the decision to fly?

2. What are the major points that should be brought to the attention of the Shuttle Management and the NASA Administrator, and what will provide the Administrator with the best visibility into the risk assessments made to date?

3. Has the review system really done the job at each level of the ALT program, from contractor to NASA Headquarters, and is the aggregate risk really understood (including the subjective summation of apparently non-major type risks)?

4. To what degree are the steps followed in reaching ALT safety assessment being applied to the many elements that make up the OFT first mission?

Background data was gathered from the following documents:

1. ALT (Approach and Landing Tests) Project Safety Assessment, JSC 10888, latest issue.

2. Technical Assessments examining ALT safety hazards.

3. Space Shuttle Program Safety, Reliability and Quality Assurance Plan-Level II, JSC 10681.

4. Space Shuttle Program System Level Open Problem List, JSC 09925.

5. Orbiter Open Problem List/Technical Issues, JSC 09079.

6. ALT Critical Design Review RID list.

7. Selected PMIR Action Items relating to S, R&QA activities.

The team then reviewed the adequacy of the data base for these reports as well as management use of these reports to assure knowledgeable risk management.

Given the magnitude of the work necessary to adequately examine and evaluate the S, R&QA systems a sampling method had to be employed. Members of the team participated in the S, R&QA Major Safety Concerns Screening Board meetings, and Orbiter Configuration Reviews. Discussions were held with NASA and contractor personnel and many of the questions and answers are reported in other sections of this chapter.

B. Observations

1. Orbiter Project-Problem Reporting and Corrective Action.

Discussions with the Quality Engineering Branch at JSC went into details of the Problem Reporting and Corrective Action System

(PRACAS) covering the following areas:

a. Background, purpose, requirements for reporting.

b. Relationships and data flow.

c. Reports and problem resolution.

Problem reporting and corrective action systems have been established by all three NASA Centers, JSC/KSC/MSFC, and as far as can be determined at all the element contractors as well. Their mode of operation may differ but their purpose and end products are all similar. Therefore, at this time the Orbiter system was considered as the sample system. The way the system works for an element is shown in Figure VIII-1 on the Orbiter program. Those problems of a "systems or integration" nature are handled as shown in Figure VIII-2. The Orbiter contractor reporting requirements are shown in Table VIII-I.

It is important that this system provide prompt visibility of problem so their impact can be assessed and management can take appropriate action. Therefore, it is worth noting that 80% of the problem notifications occur within the 24 hour standard and the remaining 20% are reported within a few days of occurrence.

System level problems for major end items and major test articles, as well as "commonality" items are reported to JSC. These for the most part have been restricted to Criticality I and II types of problems. Criticality I and II refer to those which if they occurred during actual operations would cause loss of life, loss of mission or both. The relationship between MSFC and JSC regarding problem reporting is such that MSFC reports only Level II, systems-type problems to JSC and

maintains its own Level III problems. Two documents issued as a result of these efforts are the "Orbiter Open Problem List/Technical Issues Only," JSC 09079 prepared by the Quality Assurance Division, and "Space Shuttle Program System Level Open Problem List with S, R&QA Remarks," JSC 90025, also prepared by the Quality Assurance Division. A sample page from the first document is shown in Figure VIII-3 and one sample from the second document is shown in Figure VIII-4a/4b. This effort is supported by an information flow system using a JSC CYBER computer system with terminals at the NASA resident offices and operational sites, MSFC, KSC, RI/SD and DFRC by the end of 1977.

data base is at JSC as the focal point for this work. The sections of these reports which provide the needed visibility to various levels of management are kept in the Management Information Centers at NASA Centers and their prime contractors. The major problem reports and their resolution are discussed at periodic reviews as appropriate.

The system is described in further detail in the following documents:

(a) NHB 5300.4(1D-1) sets forth the requirements for contractors to provide a closed-loop system for the reporting of all problems and the establishment of corrective action, (b) Volume V, JSC 07700, Level II requirements define problem reporting and corrective action information requirements for all elements of the program, (c) JSCM 5324A and JSC 09296 describes the JSC on-site system, and (d) NASA/RI contract NAS 9-14000 Information Requirements Descriptions defines the Orbiter project implementation.

2. Materials Analysis Tracking and Control (MATCO)

Given the Panel's background, the Panel emphasizes the importance of controlling the materials used in and around space vehicles. The team, therefore, reviewed the MATCO system for identifying, assessing and controlling materials in their application in Shuttle.

MATCO is one of the building blocks for safety and reliability analyses and assessments since it takes all of the materials information noted below and documents it for quick identification, tracking, retrieval and control. MATCO also provides "Acceptable Materials Lists" or the "directory" in order to assist design personnel.

- Flammability, toxicity, vacuum thermal stability, hazardous fluid compatibility, age-life, stress corrosion, and fracture control.

There have been some problems in obtaining all the materials data from all the elements of the program and inserting them into the MATCO format. The current status of the MATCO program is that Rockwell International/SD met all MATCO requirements for the ALT Orbiter 101 in January 1977. MSFC has been granted a MATCO delay until 1980; however, a JSC audit of the MSFC position conducted in June 1976, indicated that MSFC is in fact reviewing all drawings and related documents to assure compliance with program materials requirements.

Further details on the system can be found in the following documents:

a. Level II requirements are established in Volume V and

Volume X of the JSC 07700 series of documents. These requirements are specified in greater detail in JSC-SE-R-0006B document, "NASA JSC Requirements for Materials and Processes" and the Information Requirement 2EN-13, "Worksheets, Standard and Accountability Control, Tracking Information and Data on Material."

b. Level III requirements are established through Rockwell International Document SD72-SH-0090B, Information Requirement Document RA-306T2, "Space Shuttle MATCO Information and Data System."

c. Level IV requirements for the Orbiter are established in RI/SD document SD-72-SH-0172, "Space Shuttle Orbiter Materials Control and Verification Plan."

3. Approach and Landing Test (ALT) Project Safety Assessment.

This assessment is published in the JSC 10888 document. It provides management an assessment of the Shuttle Carrier Aircraft crew escape system and aircraft modifications, Orbiter, GFE, Flight and Ground Operations. The systematic approach that is used is portrayed in the fault-tree schematics shown in Figure VIII-5a, b, c, d, e and f. Orbiter systems that are not in operation during ALT are not addressed and analysis of the 747 is limited to modifications made for ALT. GSE is analyzed for single failure points that could cause damage to the ALT hardware. The safety concerns selected for inclusion stem from JSC Safety Division activities, including the SR&QA Major Safety Concerns "Screening" Board. They are chosen on the basis of criticality, credibility and significance for aggregate risk. Those risks that fall in the category of "accepted risk" are of most interest.

Other categories of major interest are the impact of newly defined safety concerns on those already considered "closed," and the qualitative evaluation of the aggregate risk.

The safety assessment shows there are three accepted risks considered major concerns:

a. Smoke sensor provision in the orbiter crew cabin for ALT.

b. Single elevon hydraulic actuator.

c. Bird impact with the orbiter windshield.

The remainder of known accepted risks are as follows:

a. The crew cannot escape from Shuttle Carrier Aircraft in-flight if it is not in a stable mode.

b. There is a materials incompatibility of the 747 with the ammonia which is used as a coolant.

c. The vertical stabilizer is vulnerable to damage from the orbiter ejection panels released during captive flight.

d. The lack of "rip-stop" construction in landing gear switching valves introduces some hazards.

e. A failure in the pressure transducer tube would release the hot turbine gases.

f. There is a possibility for tank rupture in the APU hydrazine system, gaseous oxygen and hydrogen tanks and ammonia boiler system/ammonia tanks.

g. There is no relief capability for a buildup of the fuel cell coolant pressure.

h. There is a lack of redundancy in the severance system for the inner hatch.

i. The redundant pyrotechnic wiring in fact uses common cables/connectors and thus is not redundant at those points.

j. There may be situations where there is not suffient time to engage backup flight control system.

k. The "nosewheel steering fail" light may give erroneous signals.

The program has carefully considered each of these and the program feels it has an adequate rationale for accepting each one. This rationale is outlined in the report, (JSC 10888 document).

The Project Safety Assessment also summarizes the results of sneak circuit analyses. Sneak circuit analyses proved valuable on previous programs. The work on the Orbiter for ALT is being done by Boeing for the system contractor and their supporting elements. As noted in the Safety Report, sneak circuits occur when current flows through unexpected paths, at unexpected times thereby causing ambiguous or false displays or unintentional operating conditions. Since these conditions could damage equipment, inhibit an operation, cause inadvertant operation, or present erroneous data, the systematic search and identification of them means management can take the appropriate action.

4. ALT Project Safety Plan

This document, JSC 11031, "Approach and Landing Test Project Safety Plan" defines the safety organization, establishes safety policy and establishes safety responsibilities. JSC provides overall ALT safety management, monitors the implementation of safety policy, regulations, and plans, and provides safety group for the SCA/Orbiter

flight operations and orbiter flight operations. The ALT Manager ensures that safety policy and plans are implemented. KSC then provides safety management for orbiter ground operations and DFRC provides safety management for SCA ground and flight operations and serves as focal point for safety coordination with Edwards Air Force Base. The Rockwell Space Division complies with contractural safety requirements and supports JSC, KSC, and DFRC in conduct of safety tasks.

5. ALT Major Review RID Status.

To test the effectiveness of the RID system in handling safety concerns, the Panel asked about the number of Review Item Descrepancies (RID) from the ALT Critical Design Review still open after nine months. The response showed that only 19 of 44 RID's from the CDR board were still open as of October 28, 1976. All RID's which impact the first captive inactive flight have been closed. Six RID's which are open at the time of this report are not a constraint to that flight.

6. Task Team Questions and JSC Responses

The team also raised the following technical questions or concerns for consideration by the JSC Safety, Reliability and Quality Assurance Office. The questions and answers are provided below.

Q. Is there any identifiable concern with the Microwave Scanning Beam Landing System (MSBLS) that could affect the ALT program with mated or free flight? For example, accuracy, reliability of operation, and integration into a combined autoland with possible manual takeover?

A. The MSBLS provides data for glide slope, bearing, and slant range. MSBLS data is provided to the guidance and control to facili-

tate automatic landings and to the horizontal situation indicators in the cockpit which are used as navigation aids for manual landings. Manual landings are currently planned during ALT flights with temporary engagement of the autoland system at higher altitudes. The MSBLS provides elevation and azimuth angles within $\pm$ 0.05 degrees and slant range within $\pm$ 100 feet. Single MSBLS data is not used until after separation, there are no concerns associated with mated flight activities.

The Safety Division has conducted a hazard analysis of the MSBLS and conducted inspections of the DFRC facility. Several issues are being tracked as a result of these activities. These include (1) the inability to verify antenna pointing and distance measurement accuracy in the relatively short period between orbiter drops and shuttle training aircraft runs, (2) unexplained deviations in antenna pointing accuracy which have occurred at DFRC, and (3) inability to verify the MSBLS ground station accuracy because ground station errors cannot be separated from overall system errors. Recommendations to resolve Items 1 and 2 above have been submitted to the tracking and communications development division. Studies have been directed to resolve the third issue as a result of several RID's submitted at the ALT CDR conducted in April 1976.

No issues have been identified relative to reliability of operation because of system redundancy, the short duration of the orbiter free flight, and the various system verifications, including those performed during the captive/active flights.

Delivery of waveguides has been impaired because of poor quality control. Rejection of waveguides has delayed start of qualification tests. If problems continue, certification of wave-guides for ALT may be impacted.

No issues have been identified relative to MSBLS integration into a combined autoland with manual takeover. Since MSBLS data is always displayed in the cockpit, there is no real transition in MSBLS when going from auto to manual.

Q. An ALT data-link systems review was conducted earlier at Palmdale. It was to serve as the final review of the total ALT microwave data system. What part was played by the S, R&QA people?

A. JSC, DFRC and RI/SD R&QA were present at the review and Safety was represented at the review. The review covered site activation planning and results of recent tests of the microwave system. Presentations were made by Pacific Telephone, GSFC and RI/SD. The minutes of the review have not been released at the time this is written although JSC ground data systems personnel have indicated that no major constraints were identified. This system is under contract to GSFC. JSC, SR&QA personnel do, however, support activities such as the ALT flight and ground operations planning group meetings where planning and issues associated with the data-link system are discussed. Although the system is required for integrated testing and system verification during ALT, it is not considered safety critical. Malfunction of the microwave link or the complex at Palmdale prior to the GO/NO GO transmission from Palmdale would result in a mission scrub. The

system is not safety critical during Orbiter free flight.

Q. What tests are to be conducted to prove that the tailcone will stay affixed to the orbiter during mated flights? What would happen if the tailcone were to become partially and/or totally detached from the orbiter either during mated or during free flight?

A. The tailcone and its attach fittings are designed and certified for flight exactly like all other orbiter structure. All orbiter structure for ALT is certified primarily by analysis such as flight loads analysis, internal loads analysis, stress and fatigue life analysis, and flutter analysis. Tests that will be conducted to supplement these analyses include extensive wind tunnel tests and a mated orbiter/SCA ground vibration test. Also, because structural verification tests will not be conducted for ALT, the ALT flight operations will be restricted to ensure that the maximum flight loads on any portion of the orbiter structure do not exceed 75% of the limit load predicted by analysis.

Q. Have you considered the use of instrumentation such as simple bridging wires that would give you an early warning of a possible separation of the tailcone so that you could get back safely?

A. This sounds like a reasonable approach and will now be investigated. This was reviewed subsequently by RI/SD and determined not to be necessary because the analysis and ground testing were sufficient.

Q. If ammonia is being used anywhere on the Orbiter, is it safely vented overboard to preclude injurious effects on the orbiter or the 747?

A. The Ammonia Boiler System (ABS) for orbiter 101 consists of

two systems, designated "A" and "B", each containing three K-bottles each. The bottles in each system are manifolded into a single line feeding through a solenoid isolation valve, a flow control valve, and finally into the ammonia boiler. The boiler exhaust port is located on the right aft fuselage at the base of the vertical tail and is directed upward. Maximum flow rate through the boiler exhaust will be approximately 2.25 pounds per minute.

An assessment of orbiter 101 materials compatibility with ammonia has been performed by Rockwell/Space Division. Under normal operating conditions, (assuming no tank/line ruptures), the Orbiter will be exposed to ammonia vapors only. Periodic inspections will be performed to verify normal operation. The fuselage, wings, and vertical tail are aluminum alloys containing less than 6% copper and are generally unaffected by ammonia. The crew module aluminum contains 6.8% copper, but is primed and painted and is thus protected. Electrical wiring and equipment are environmentally sealed. Rockwell/Space Division's assessment of both the fused silica tiles and the polyurethane Simulated Reusable Surface Insulation shows no anticipated incompatibility with ammonia.

As a result of orbiter 101 delta PDR RID 09.02.70, "Effects of Orbiter exhausts on Carrier A/C and Crew," an assessment was made on the 747 materials. The systems and components investigated included engine, APU's, air conditioning system, vertical tail structure, wiring and mechanical components, fuselage structure, and internal electrical systems. At the concentration of ammonia vapors predicted, no problems

are anticipated. Aluminum has a corrosion rate of less than 1 mil per year for exposure to moist ammonia gas up to 212° F. Dry ammonia has no appreciable effect on aluminum.

7. Additional items of interest.

Another area of interest was the position of the hydraulic system lines, system-to-system, since the anomaly on the Orbiter 101 landing gear test proved that when hydraulic lines are positioned near one another there is a chance that anything that causes line failure in one can adversely affect others.

The program is reviewing the effectiveness of rudder and elevon rates and aerodynamic control qualities at this time and this will be followed by the Panel task teams.

Another area of continuing interest is the low APU fuel capacity inherent in the Orbiter 101 which makes it necessary to have the APU's turned off and on during the flight.

C. Information Update

A number of items have been of interest, e.g., contingency abort capability and planning, lightning protection, etc., which have been addressed since the task team reviewed the status of the Safety and Reliability aspects of OFT flight. This data could be placed under the OFT section of this report as well as in this section.

In continuing its review of abort planning and capability, with resultant risk or no risk acceptance, the Panel feels that it would be worthwhile to identify requirements for aborts other than those currently specified...Abort to orbit (ATO), return to launch site abort (RTLS), and Abort once around (AOA).

Lightning protection has been discussed in Section XII, External Tank and Solid Rocket Booster, and has been a subject of discussion in previous Panel reports. Because of the number of program initiated studies and the desire to make the Shuttle system as independent of environmental factors as possible, the panel will examine the results of the many activities now in process.

The emphasis being placed on the testing of the hydraulic system as a whole and the major components to assure safe and reliable operation during the Orbiter 101 and 102 flight activities will continue to be followed to help assure that nothing falls-through-the-crack. Areas such as the Dynatube connections which must be leak-tight(do you lock-wire these connections or not?), the fidelity of the test configurations in regard to the actual flight equipment (credibility of test results?),

maturity of the hydraulic circulation pump (is the performance really known under operational conditions?), and the degree of instrumentation on actual first flights during which the total hydraulic system is to be operated.

TABLE VIII-I

ORBITER CONTRACTOR PROBLEM REPORTING REQUIREMENTS

Problem Notification---	All problems that occur during or subsequent to acceptance test shall be reported to JSC within 24-hours of occurance.
Problem Documentation--	A documented report shall be provided to JSC within 5 days of the reportable item identification.
Problem Disposition----	A documented report shall be submitted 21 work days after initial report to document the cause and corrective action or rationale for not implementing corrective action.
Open Problem List------	A report shall be submitted weekly beginning 21 days after the start of the certification program listing all open reportable problems and the status of actions being taken to resolve each.

FIGURE VIII-1

ORBITER PROJECT PRACAS RELATIONSHIPS

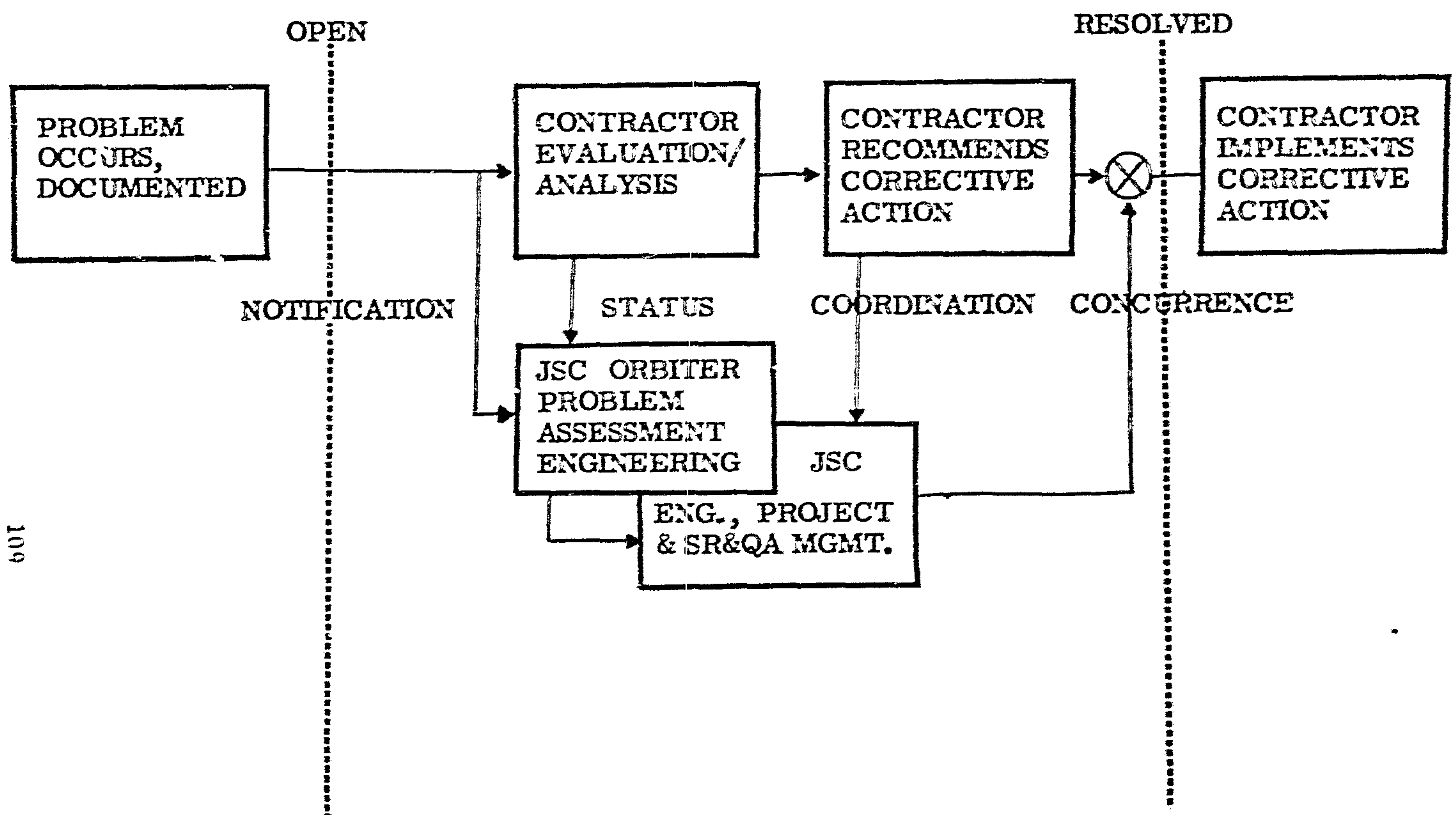
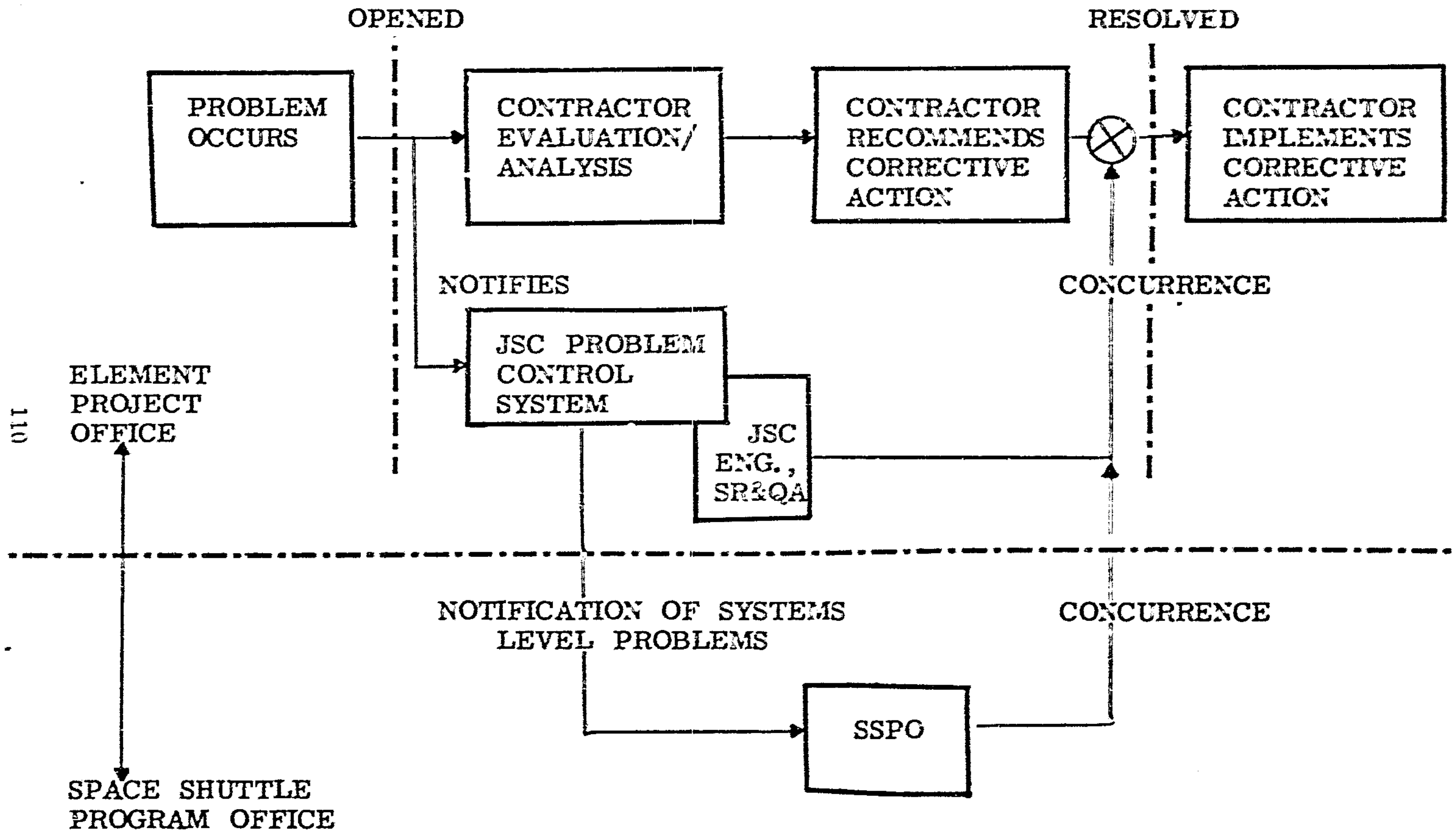


FIGURE VIII-2

SPACE SHUTTLE INTEGRATION PROBLEM REPORTING AND CORRECTIVE ACTION SYSTEM



9/21/76 JSC SHUTTLE OPEN PROBLEM LIST-TECHNICAL ISSUES PAGE 1
ADC ORBITER - DISPLAYS AND CONTROLS

ACTION ASSIGNEE: D.DUSTON SSH/TM: EG2/A.J.FARKAS

PROBLEM IDENTIFICATION:

LEVEL	TYPE	VEHICLE ON	CAUSE	FAIL MODE	TEST/OPER	PREVAIL. COND.	LOCATION	OCCURRED DATE	REPORT NUMBER
ELEMENT	UNSAT COND	101	DES- -	OUTPUT FALSE	CKO	FUNCTIONAL	RIPLM	05/28/76	A2768-01

HARDWARE IDENTIFICATION:	PART NUMBER	PART NAME	MFG	SERIAL/LOT	DATE/TIME UPDATED	REFERENCE
TEST ARTICLE	V070-008002-101	ORBITER GENERAL	RIDNY	0101	09/21/76 133843	
NONCONFORMING ARTICLE	V070-008002-101	ORBITER GENERAL	RIDNY	0101		
NEXT HIGHER ASSEMBLY					RESOLUTION DATE	WORK UNIT CODE
					09/17/76	

PROBLEM EFFECTIVITY:
MISSION NUMBER ALT
VEHICLE NUMBER 101
CRIT - STATUS 3- EXPL

PROBLEM DESCRIPTION:
DURING THE OV-101 FIRST POWER APPLICATION TO INSTALLED FLT COMPONENTS, USING FLIGHT WIRE HARNESSES AND DURING THE FIRST TEST CONDUCTED PER TCP MLO720-4501-101, POWER REACTANT SUPPLY AND DIST. AND POWER GEN. FUNCT. C/O THE MC432-0222-0016 EVENT OMD/ SM 65042-320016133 FOR FUEL CELL POWER PLANT NO. 2, H2 REACTANT SUPPLY VALVE (MC284-0429-0280) ON COCKPIT D AND C PANEL R2 MOVED HALFWAY BETWEEN GRAY AND BARBER POLE INDICATION WHEN THE VALVE WAS COMMANDED FROM OPEN TO CLOSE BY SWITCH S-29(ME452-0102-6205. THE EVENT IND. SHOULD BE FULL BARBER POLE. 1-THE SWITCH S29 WAS SUBSEQUENTLY CYCLED TO OPEN AND CLOSE THE VALVE

ANALYSIS:
A TOTAL OF 14 ON/OFF CYCLES. AFTER THE FIRST CYCLE THE ANOMALY DISAPPEARED AND DID NOT RECUR. 2-NONE. 3-THE ANOMALY OCCURRED DURING THE OV101 FIRST POWER APPLICATION TO INSTALLED FLIGHT COMPONENTS AND USING FLIGHT WIRE HARNESSES. 4-ANALYSIS INDICATED THE MOST PROBABLE CAUSE IS INTERNAL STICKING OF THE INDICATORS MOVEMENT, CAUSED BY A FOREIGN PARTICLE, WHICH AFTER ONE CYCLE WAS DISPLACED PERMITTING THE INDICATOR TO FUNCTION NORMALLY. 5-LAST TEST IS THE NORMAL PRE-FLIGHT SYSTEM READINESS CHECK. 6-ANOMALY CAN BE DETECTED ON THE GROUND VIA PCM DOWNLINK AND CREW CAN OBSERVE THE O2 REACTANT

RESOLUTION:
VALVE INDICATOR (COMPARISON) TO EVALUATE THE CONDITION IN REAL TIME WHEN COMMAND IS SENT. 7-MISSION EFFECT-NONE. THERE ARE NO SAFETY HAZARDS INVOLVED WITH A RECURRENCE OF THIS ANOMALY. 8-A FAILURE OF THE INDICATOR WILL NOT EFFECT THE OPERATION OF THE FUEL CELL POWER PLANT. IT IS POSSIBLE THAT THE FUEL CELL DAMAGE COULD OCCUR IF REACTANT IS SUPPLIED TO ONE INLET ONLY; HOWEVER, THIS WOULD REQUIRE AN ACTUAL VALVE FAILURE IN ADDITION TO THIS ANOMALY (SECOND FAILURE) . THE CREW CAN EVALUATE THE CONDITION REAL TIME WHEN THE COMMAND IS SENT BY COMPARING THE O2 AND THE H2 REACTANT VALVE INDICATION. 9-NONE. 10-THE -0016 INDICATOR IS FOR OV101 ALT USE ONLY.

ACTION ASSIGNEE: G.FLETCHER SSH/TM: EG2/A.J.FARKAS

PROBLEM IDENTIFICATION:

LEVEL	TYPE	VEHICLE ON	CAUSE	FAIL MODE	TEST/OPER	PREVAIL. COND.	LOCATION	OCCURRED DATE	REPORT NUMBER
ELEMENT	FAILURE		MFG- -	FAILS OPEN	QAL	LIFE	EDISEL	06/11/76	A4543-01

HARDWARE IDENTIFICATION:	PART NUMBER	PART NAME	MFG	SERIAL/LOT	DATE/TIME UPDATED	REFERENCE
TEST ARTICLE	MC452-0134-0007	SWITCH THUMBWHEEL DS	EDISEL	0001	09/09/76 163416	
NONCONFORMING ARTICLE	MC452-0134-0007	SWITCH THUMBWHEEL DS	EDISEL	0001		
NEXT HIGHER ASSEMBLY					RESOLUTION DATE	WORK UNIT CODE
					ES: 09/24/76	

PROBLEM EFFECTIVITY:
MISSION NUMBER ALT
VEHICLE NUMBER 101 101
CRIT - STATUS 3- OPEN 3- OPEN

PROBLEM DESCRIPTION:
UNABLE TO CHECK SWITCH ELECTRICALLY, UNABLE TO MAKE CONTACT WITH SWITCH INTERNALLY.

REMARKS:

FIGURE VIII-3

SIGNIFICANT PROBLEMS

RESPONSIBILITY: SUBSYSTEM MGR. W. SIMMONS SR&Q A ASSIGNEE W. HARVEY	DATE REPORTED 9/23/76 EST. RESOLUTION 10/12/76	PROBLEM REPORT: A5598	PART NUMBER: MC 325-0034-0012

ITEM: ONE WAY TRANSFER PYRO-DEVICE, CREW ESCAPE ENERGY TRANSFER SYSTEM

CRITICALITY 2

PROBLEM:

DURING LOT ACCEPTANCE TEST FIRINGS OF ONE-WAY TRANSFER, ONE UNIT FAILED TO FIRE HIGH ORDER AT AMBIENT CONDITIONS (EXPLOSIVE MIX DEFLAGRATED OR BURNED INSTEAD OF DETONATED). THIS LOT WAS BEING RETESTED AFTER A REBUILD DUE TO SIMILAR PROBLEMS WHICH OCCURRED 6/9/76. ORIGINAL PROBLEM WAS NOT DUPLICATED IN FAILURE ANALYSIS, BUT PRIMER POCKET WAS REDESIGNED AND PRIMERS WERE 100% SCREENED AS A CORRECTIVE ACTION.

EFFECTIVITY:

OV-101 & OV-102

SCHEDULE IMPACT:

SERIOUS IMPACT ON HARDWARE NEED DATE OF 10/25/76 FOR CREW ESCAPE SYSTEM BREADBOARD TESTS AT ROCKWELL AND SLED TESTS AT HOLLOMAN (STATIC 1/12/77)

STATUS:

Ø SEVERAL DESIGN INTERFACES HAVE BEEN CHANGED: (SEE ATTACHED DRAWING)

A) PRIMER CHANGED TO SAME TYPE USED ON TIME DELAYS - M4201 INSTEAD OF M4202
B) PRIMER FLASH HOLE DIAM. DECREASED
C) L/D COLUMN RATIO OF LEAD AZIDE REVISED TO 2.0 FROM 1.0 AND COLUMN LOAD PRESSURE REDUCED.
D) HNS "PANCAKE" FOLLOWING HNS OUTPUT CHARGE INCREASED TO 0.09 IN. FROM 0.03 IN.

Ø SECOND SOURCE VENDOR UNDER CONTRACT - QUAL DATA FOR F-14 DEVICE WAS REVIEWED 10/12/76 BY JSC & ROCKWELL AND CONSIDERED ACCEPTABLE WITH EXCEPTION OF TWO DESIGN PARAMETERS WHICH WILL REQUIRE WAIVERS (SEE ACTION REQUIRED). RI HAS PURCHASED PARTS FOR BREADBOARD TESTS.

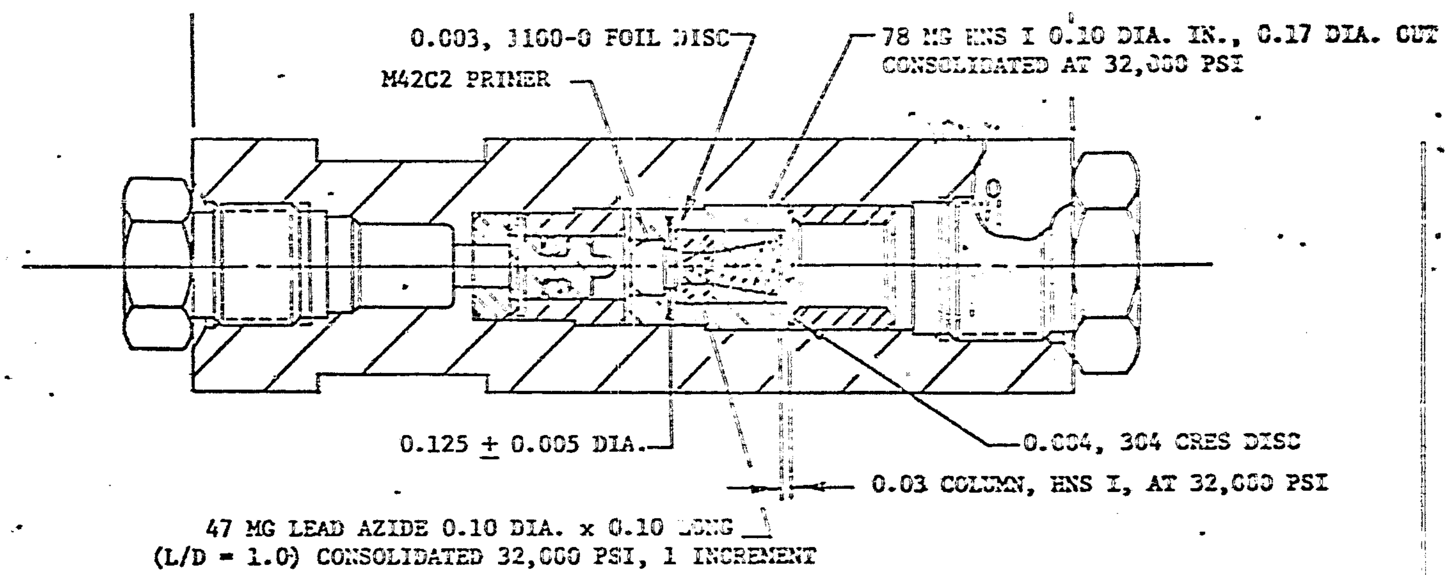
ACTION REQUIRED:

Ø AT EXISTING VENDOR: REDESIGN DEVICE AS DESCRIBED ABOVE AND PERFORM LAT. (ROCKWELL TO CONTINUE PARALLEL EFFORT UNTIL F-14 WAIVER APPROVAL IS IMMINENT).

Ø AT SECOND SOURCE VENDOR: A) RI TO REVIEW AND FORMALLY APPROVE DOCUMENTATION INCLUDING ATP & QTP, B) REVISE SPEC. TO REFLECT NEW CONFIGURATION, C) SUBMIT WAIVERS FOR NON-GFE HNS AND NON-APPROVED (JSC 08060) PRIMERS UTILIZED IN F-14 PART.

STATUS: AS OF 10/25/76 NEW: ☐ OPEN: ☒ CLOSED: ☐

FIGURE VIII-4a



PRESENT ONE-WAY TRANSFER FITTING DESIGN

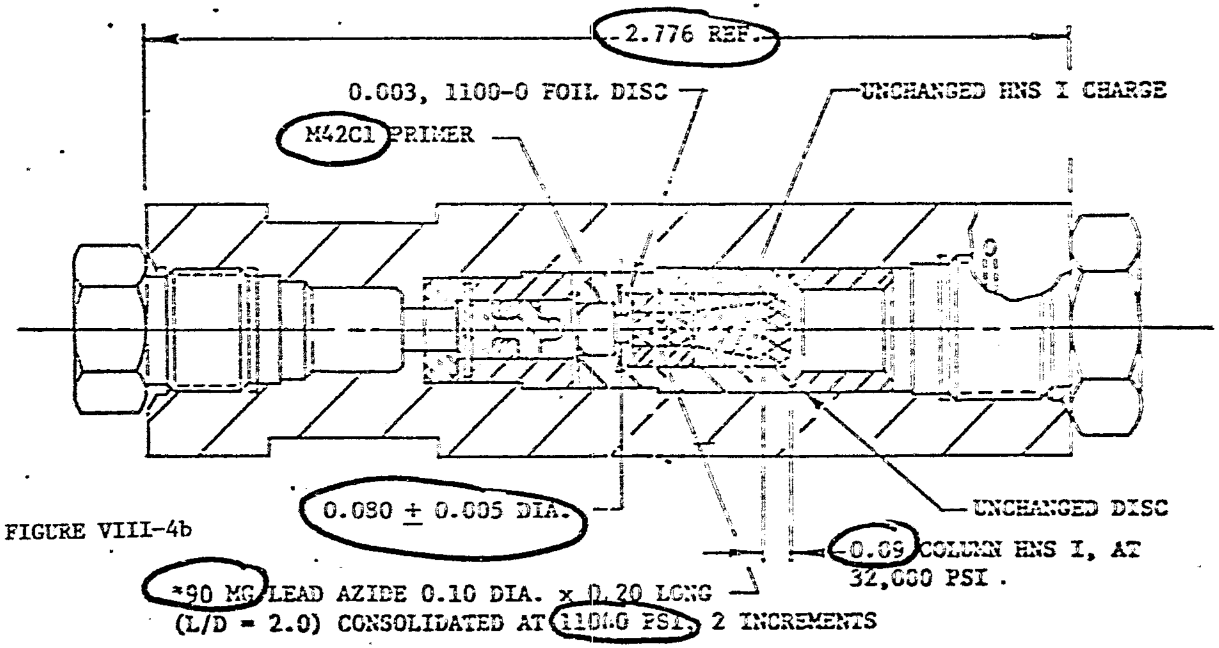


FIGURE VIII-4b

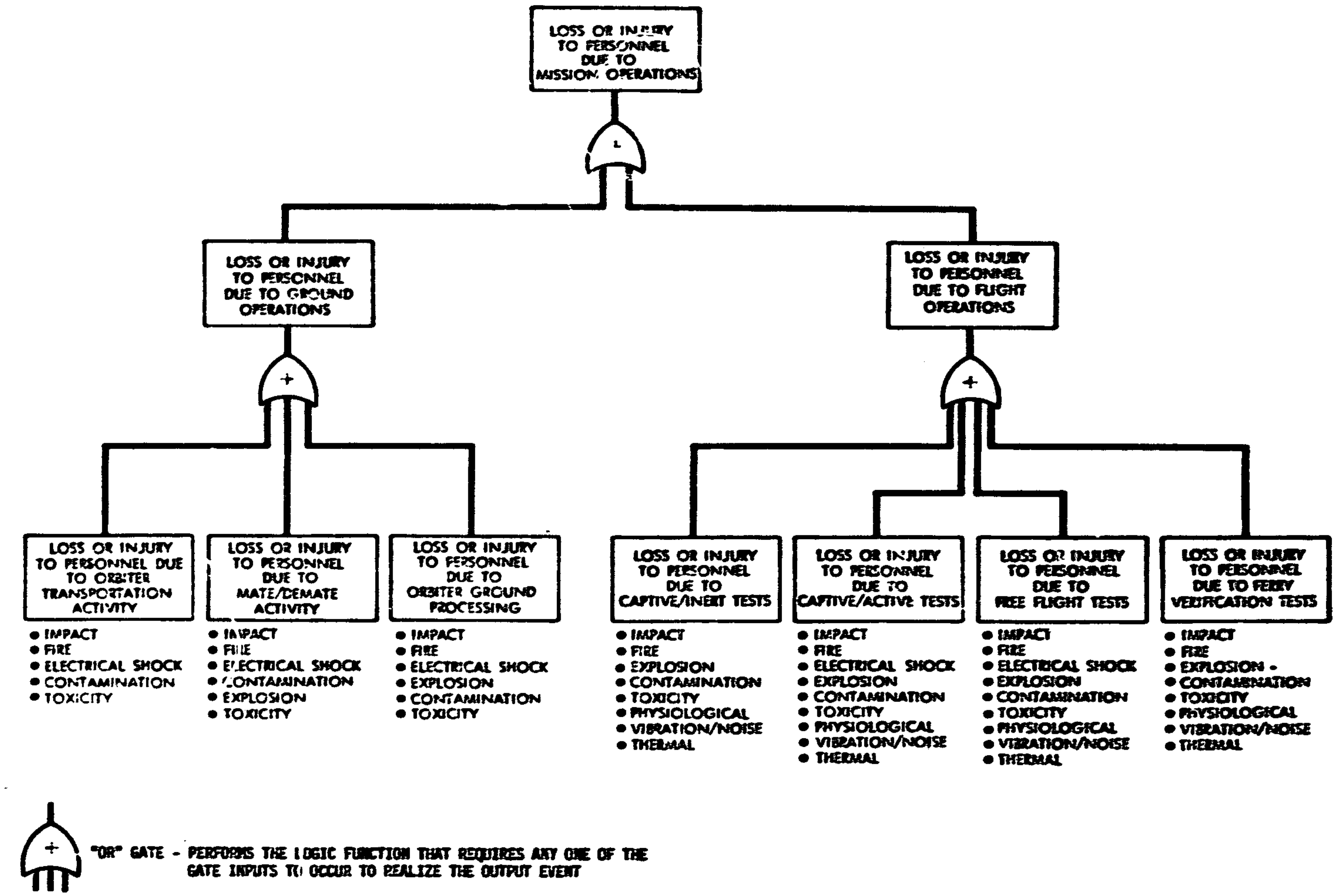


Figure VIII-5a ALT Mission Operations Fault Tree

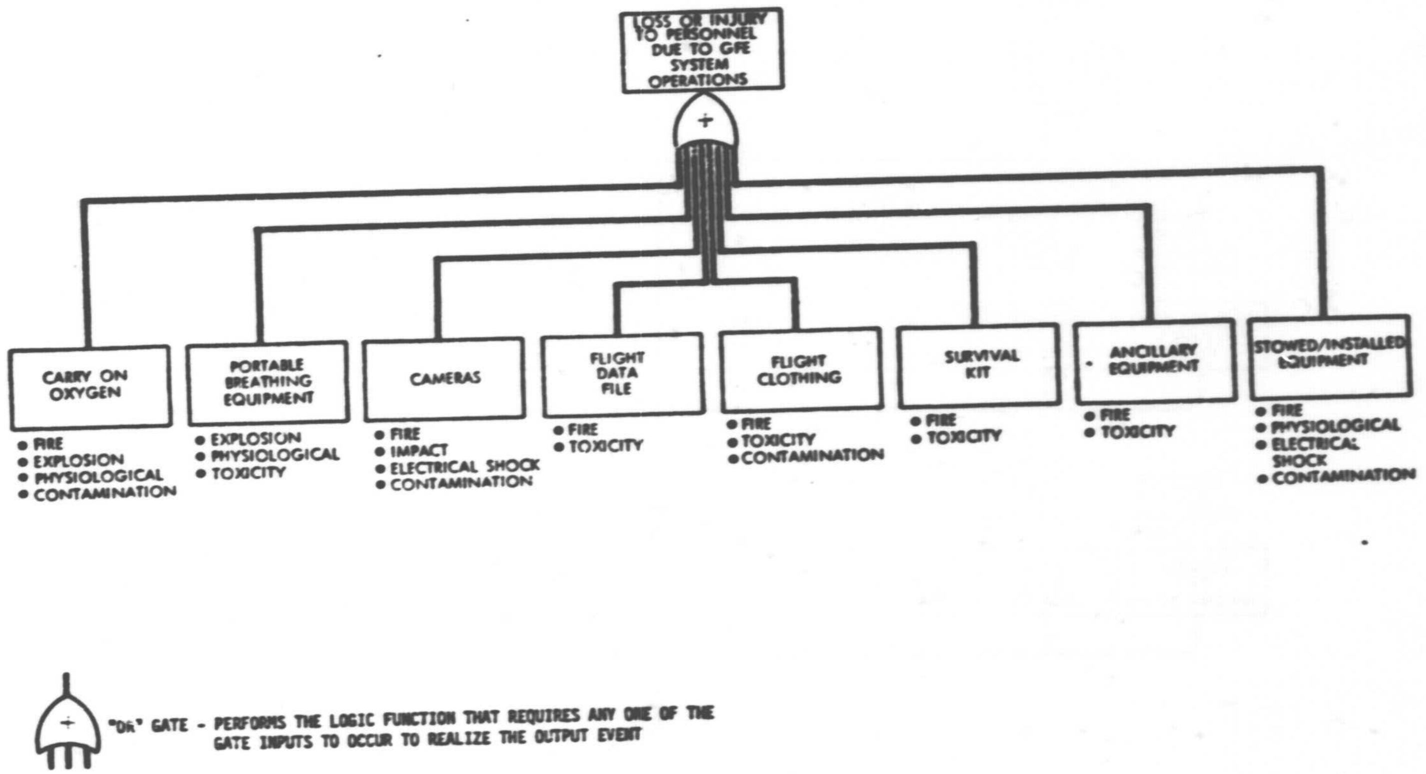


Figure VIII-5b ALT GFE Fault Tree

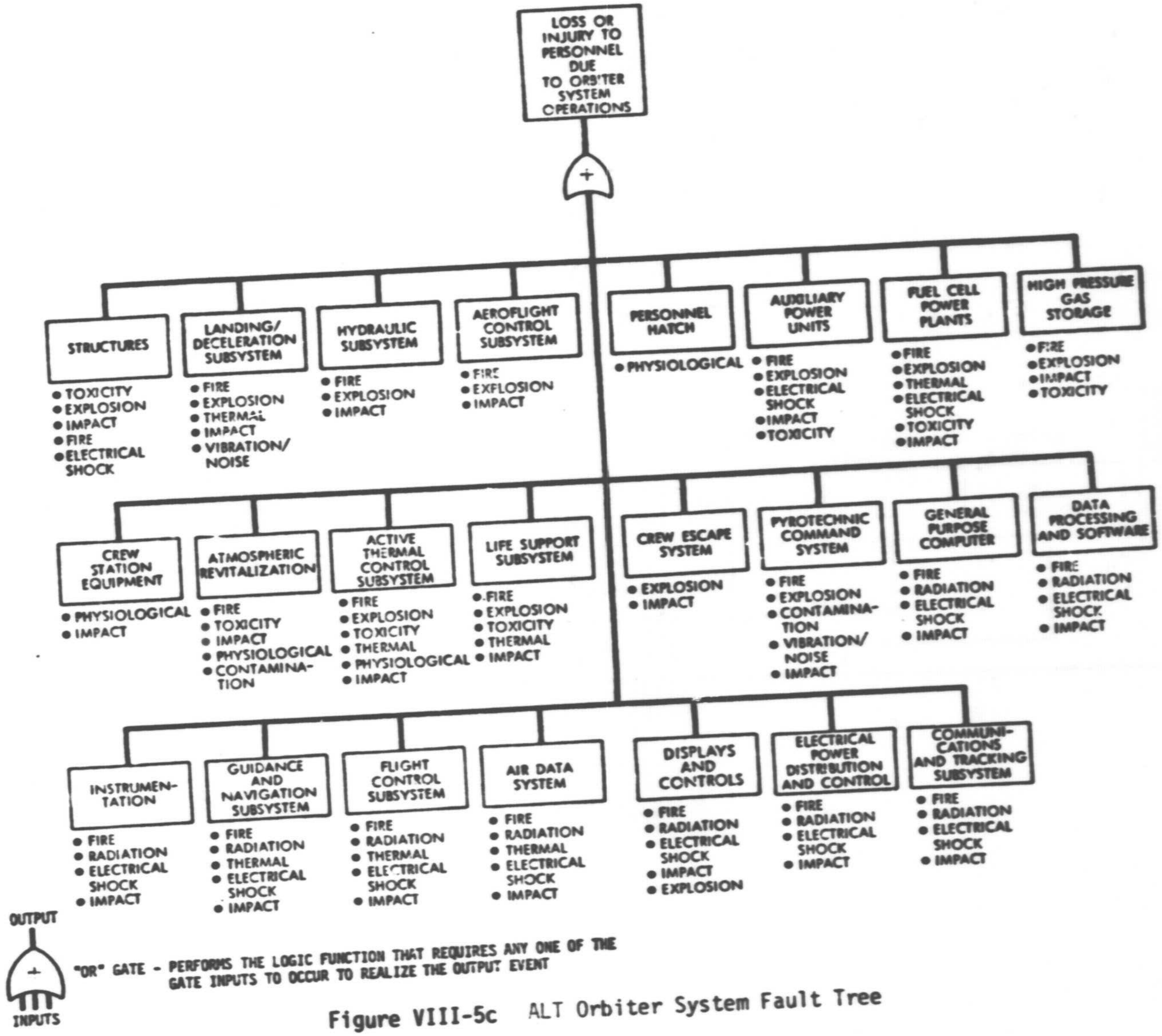


Figure VIII-5c ALT Orbiter System Fault Tree

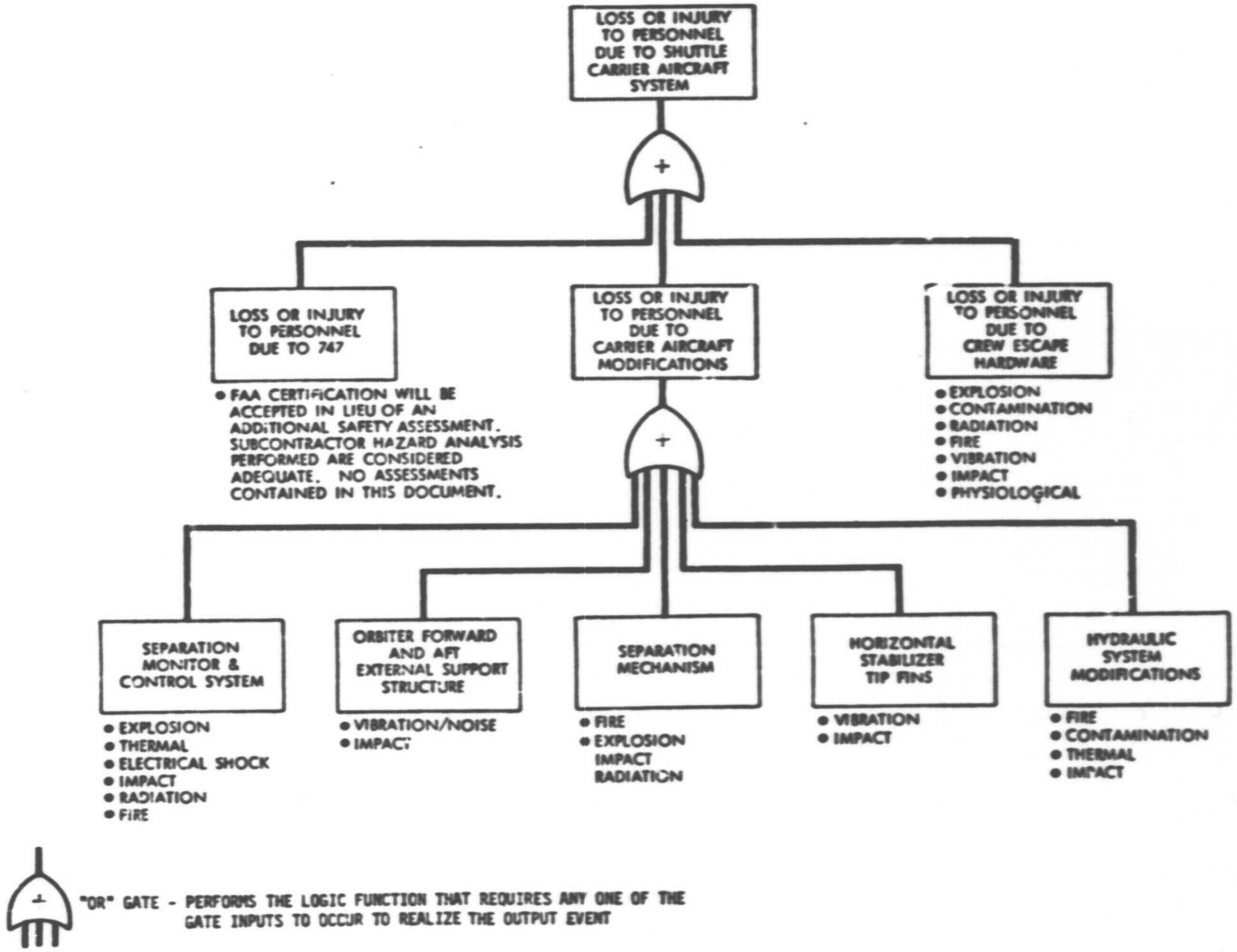
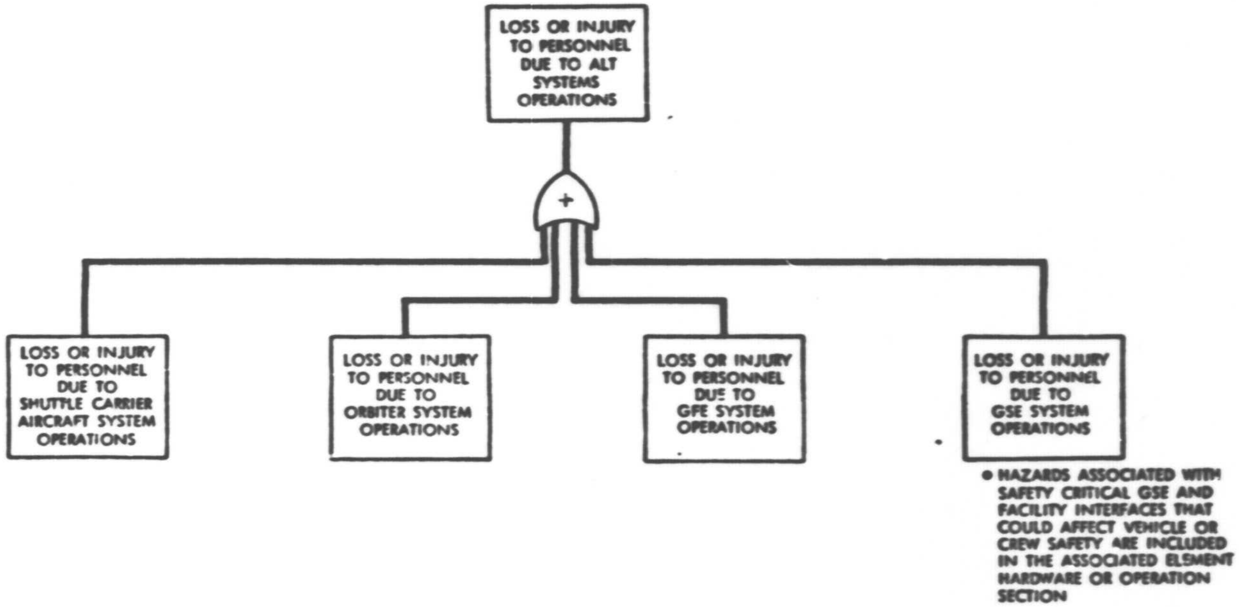
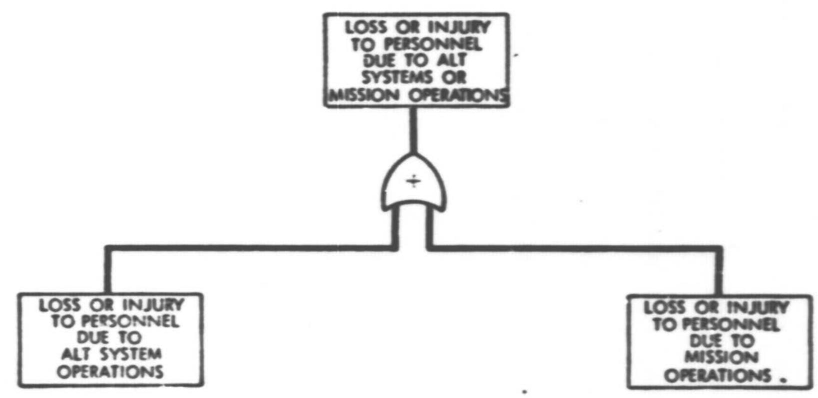


Figure VIII-5d ALT SCA Fault Tree



"OR" GATE - PERFORMS THE LOGIC FUNCTION THAT REQUIRES ANY ONE OF THE GATE INPUTS TO OCCUR TO REALIZE THE OUTPUT EVENT

Figure VIII-5e ALT System Operations Fault Tree



"OR" GATE - PERFORMS THE LOGIC FUNCTION THAT REQUIRES ANY ONE OF THE GATE INPUTS TO OCCUR TO REALIZE THE OUTPUT EVENT

Figure VIII-5f ALT Project Fault Tree

IX. CONFIGURATION MANAGEMENT AND INTERFACE CONTROL

A. Introduction

The general significance of the configuration management system for the Panel is that it assures that the program knows what is in fact being designed, built and tested so that the real risks are identified and dealt with. It forces a necessary degree of discipline on every level of a complex program and thus is an inherant technical and administrative activity of any NASA and DOD program. The system does not force the use of unnecessary paper or levels of management but does require that there be sufficient documentation to assure that management, design and user organizations have timely information necessary for effective decision making, risk assessment and program control.

Because of the significance of this system the Panel made it a point to emphasize in its last Annual Report that the Panel had not yet completed consideration of other important system integration issues such as configuration management, interface control and interaction between Shuttle system elements but that it intended to do so as soon as feasible in terms of its large workload. This section reports on the Panel's review to meet this commitment before the ALT flights. In fact the Panel felt that an examination and assessment of the Configuration Management System as it is both documented and implemented is one of the basic steps in assessing the adequacy of the ALT management system in establishing a real basis for confidence in achieving mission success and flight safety.

The Panel in designing its review of this area considered the demands the system must successfully meet.

1. The system must support the programs ability to produce hardware and software that is capable of being qualified and certified for flight, and then can be maintained, replaced, or modified as information on operational characteristics becomes available through flight tests.

2. The Shuttle Program is as diverse as its predecessors, the Apollo Program, Skylab, and the Apollo Soyuz Test Project. It has numerous prime contractors and technical support spread all over the country and there is bound to be some degree of non-standardization as well as coordination problems. These will be difficult to overcome even with the dedicated people known to be working these areas.

3. Element and integrated system aggregate risk assessments must be based on knowledge of the "as-built" and "as-tested" hardware and software. Accepted risks and their justification must also be based on such known configurations.

4. Development, qualification, and acceptance testing schedules are extremely tight and overlap with manufacture and installation requirements. Therefore, hardware and software mismatches and materiel problems, resulting from inadequate configuration management, can lead to schedule and cost impacts. Inadequacies therefore must be minimized.

Therefore, the Panel focused on the following elements of the configuration management system:

1. The system as documented.

a. Level I, II, III and IV requirements and procedures.

b. Organizational responsibilities and intercenter relationships.

c. Relationship with Master Verification Plan.

d. Configuration accounting system and repositories.

2. The system as implemented.

a. Degree of configuration control being applied to each element to determine current baselines.

b. The processing of actual hardware/software changes from inception to completion.

c. Documentation to relate the "as-designed" to the "as-built" to the "as-tested" hardware/software.

d. Activities of the Space Shuttle Program Configuration Management Panel (SSPD #6), the Level I, II and III Program Requirements Control Boards (PRCB's) and the systems engineering support provided to these activities.

e. Use of Configuration Management products to support the Space Shuttle Review system, e.g., CDR's, DCR's, and Flight Readiness Reviews.

f. The relationship between logistics (maintenance, spares, etc.) and the Configuration Management System.

g. Relationship between Safety, Reliability Quality Control and the Configuration Management System.

Since the following fundamental terms are used in this section of the report, they are defined to avoid any confusion.

1. Configuration Management System. The total system to (a) identify and document the functional and physical characteristics of all program hardware and software and the major test operations on them, and (b) control the processing of changes to the hardware, software, test functional and physical characteristics.

2. Configuration Management. The set of policies and procedures to implement the system. These must cover requirements, identification, control, accounting and verification.

3. Interface Control or Management. The specific set of policies and procedures to govern situations where one element, such as the Orbiter, is dependent on another, such as the External Tank. The interface or two-dimensional plane between elements must be designed and manufactured so that when the elements come together they match in every detail physically and operationally. The control of the internal interfaces such as between the electrical generating and distribution system and the flight control system within the Orbiter is within a single NASA Center and single prime contractor. On the other hand Interface Control is between elements which means between prime contractors and NASA Centers. Thus a change considered by the management of one element must be considered in terms of its impact on the other element and their integrated operation.

The observations that follow are based on the program responses to specific questions, direct quotes from briefing material and notes made during discussions.

B. Observations

1. General Information.

The Space Shuttle program has streamlined the configuration management methodology which evolved through Apollo, Skylab and Apollo Soyuz. Paperwork has been reduced, efficiency increased and changes made to some basic operating principles.

The four levels of the program are shown in Figure IX-1 along with the elements that make up each level. In addition there is a system of Boards - the Program Requirements Control Board (PRCB) the Cost Limit Review Boards (CLRB's) and the Change Control Boards (CCB's). These are shown in Figure IX-2.

Briefly the established prerogatives for each level are:

Level I - Program Director controlled requirements and direction.

Level II - Program Manager controlled requirements and direction that normally affects more than one project office.

Level III - Project Manager controlled requirements and direction that clearly affects a single project office.

Level IV - Project Element/NASA design activity/contractor controlled requirements implementation and direction that clearly affects only the respective element for which the design activity/contractor has responsibility.

The Program Director located at NASA Headquarters, has a single document that covers the Level I activities (Program Directive #1C, July 5, 1973, "Establishment of Change Procedures To Space Shuttle Program Requirements - Level I Control Documents.") The Program Directors Program Requirements Control Board does not meet often as most of the Level II PRCB operations are conducted at JSC with teleconference arrangements to both NASA Headquarters and other appropriate NASA Centers and contractors. During these board operations the Level I input is made informally to those managers making Level II decisions. On the other hand the Cost Limit Review Board at Level I is quite

active, meeting on the average of once eachmonth to make decisions transmitted to it via Level II or determined as necessary at Level I itself. There is no program directive establishing this CLRB and defining its operation; but, since it has been in action for some years, it is not expected to require such documentation at this late stage of the program. The Program Director in Washington uses the CLRB to control costs and the PRCB to control "reserves", i.e., computer memory reserve capacity or electrical power generation capacity reserves.

The workload at Level II requires the services of three Civil Service persons and nine RI contractor support persons. The nature of such work also requires the part-time use of technical personnel from other NASA divisions at JSC.

In addition there are Level III and IV systems at the project level that must function effectively to assure an adequate total system for decisions made here that are not reviewed at higher management levels.

Interface controls are under the purview of the Systems Integration Office at Level II and their mode of control and use follow that for normal Level II operations.

The operation of this system is discussed in more detail in the following sections.

2. Configuration Management Requirements

The basic philosophy used in developing the requirements is: "This document has been jointly developed by the Manned Spaceflight Centers, and represents a careful application of the experience gained in previous NASA, military, and commercial space and aircraft programs."

To be effective from the standpoint of producing hardware and software in a timely, orderly manner within the cost constraints, configuration control by NASA is established only "when and where it is necessary and when it will tend to stabilize program efforts. Caution must be taken to prevent premature control and control at too low a level of detail."

These requirements are set forth in JSC 07700, Volume IV, "Configuration Management Requirements," baselined March 2, 1973 and a Revision A issued in April 1974. Changes are made as required by reorganizations, personnel changes or to meet the demands of the ongoing Shuttle program. Through November 1976 sixteen changes to this document have been processed and incorporated.

The additional documentation used by the program and examined by the Panel are as follows:

a. "Level II Baseline Description and Status Report," JSC 08102, published monthly and contains about 70 pages of computer printout.

b. "Space Shuttle Orbiter/System Integration Contractor Configuration Management Plan," SD73-SH-022A, June 23, 1975 issued by Rockwell International, Space Division.

c. "Shuttle Carrier Aircraft Project, Configuration Management Manual," JSC 08140, January 13, 1975.

d. "Space Shuttle Program Configuration Management Panel," SSPM Directive No. 6A, July 3, 1974. This directive established this Panel as a mechanism for reviewing, assessing, advising and guiding the proper integration of configuration management activities across

the program.

3. Configuration Identification.

Identification refers to the manner and documentation for describing in detail all program hardware and software. Requirements and configuration are identified in detail for the practical purpose of producing hardware and software which meets or exceeds specified requirements and is a baseline used for control and accounting of changes as they occur.

The baseline at each level of the program requires those types of data shown in Table IX-I. Note that the interfaces are taken into account in these listings.

An integral part of the identification process is the assurance of hardware traceability. Traceability is the identification technique of correlating historical records to each item. These records are valuable in resolving hardware problems, understanding age-life characteristics and helping to assure reliable and safe flight and ground equipment.

To illustrate the set of documentation required for a project (Level III) here is the documentation required for the Shuttle Carrier Aircraft:

a. All the applicable requirements of the NASA Level I and II baselines.

b. Specification MJ510-0001-1, "Shuttle Carrier Aircraft Contract End Item Specification - Design and Performance Requirements." Baselined by the Shuttle Carrier Aircraft Project Manager on April 9, 1976.

c. Specification JSC-08943, "Flight Test Requirements - Volume I - Shuttle Carrier Aircraft." Baselined by Orbiter and SCA Projects on December 12, 1975.

Configuration Identification includes the Interface Control Documents (ICD's) used to control interfaces between two or more participating contractors and government agencies. In effect the ICD's augment the contractural specifications by documenting the requirements and agreements between interfacing contractors and/or NASA. The content of these ICD's can be seen on Table IX-II which is from ICD #2-17001, "Orbiter/Carrier Aircraft, Ferry and ALT. This particular ICD is unique in that two configurations are presented, both of which involve the Orbiter and the 747 aircraft, that is, ferry flights and the ALT.

Identification also includes drawings - a drawing tree for both flight and ground systems (this is in effect a directory of drawings), engineering drawings and a part number control system.

4. Configuration Control.

The baseline as established at any given time must be protected from inadvertant and/or unauthorized changes. The baseline is normally a product of such configuration reviews as the Preliminary Design Review (PDR) and the Critical Design Review (CDR). In addition to these traditional reviews, the Space Shuttle program has added a series of incremental design reviews. For instance there is a system of reviews to consider the design in light of prior testing and before proceeding to the next step of the program. These are called Customer Acceptance Readiness Reviews (CARR's) or Configuration Inspections (CI's) Thus there was a Phase I configuration inspection in the Spring of

1976 which reviewed the design in light of testing and whether it was ready to proceed through individual subsystem testing. Then a Phase II review was held in October 1976 to consider what had been learned about the design from this individual subsystem testing. A Phase III review in late January 1977 considered the proof of design in the light of integrated testing. The Phase III review authorizes the program to proceed with final testing and delivery of the vehicle.

Configuration control is maintained through strict change management. Change management is effected through the use of Configuration Control Boards (CCB's) which are shown in Figure IX-2. The Level I and II CCB's are referred to as Program Requirements Control Boards (PRCB's). The membership of these boards has been established so that every change request receives a thorough going-over by the board and by the supporting technical and administrative groups. For instance, the Level III Orbiter CCB is supported by the Orbiter Configuration Control Panel, the GSE Configuration Control Panel, Orbiter Software Design Review Board and those Technical Status Reviews required as a part of the normal technical design information flow between NASA and its contractors.

The change control flow is shown schematically in Figure IX-3. One should note the placement and use of the CLRB which is a distinct change from previous programs. The Level I PRCB contains about 10 members, while the Level I CLRB contains 6 members. The Level II PRCB contains about 29 members and the Level II CLRB contains only 5 members. Each level, of course, has its own authorities and responsibilities and the PRCB and CCB's control all items

not affecting the next higher level of management. However, in the case of high cost items, the CLRB operates concurrently with the PRCB and quoting from Volume IV, JSC 07700, Page 4-4, "The Level II Cost Limit Review Board is the controlling authority for all Level III changes with projected expenditures which deviate from program and project cost plans by more than $500,000 in any fiscal year. All Level III changes with a dollar value in excess of $500,000 in any fiscal year shall be dispositioned by the Level II CLRB and, if approved, shall be forwarded to the Level I CLRB for dispositioning. Level II changes with a dollar value exceeding $500,000 in any fiscal year, or $1,000,000 total for payload related changes shall be processed through the Level II PRCB or CLRB; and, if approved, forwarded to the Level I PRCB or CLRB for disposition. Level I changes regardless of dollar value are forwarded to the Level I PRCB for disposition."

It was noted that in the case of the Shuttle Carrier (the 747), the dollar value was different. Level II is to be notified by a memorandum from the SCA Project Manager when the change value exceeds the figure of $300,000 at any time.

The Panel task team examined samples of changes transmitted to the CLRB as well as the minutes of such Boards. The system appears to be working well and the degree to which encumberances slow down the system is not known at this time. However, the personnel with which this was discussed indicated that no time was lost in the process and it may even preclude things from "falling into the crack." Since the same paper is used at each level, the amount of paper is not too great and the approvals are readily apparent. The task team

examined a number of PRCB Minutes and Directives to ascertain the depth of material covered, action items and distribution. A sample "change package" was selected (actually several were examined) at random to provide an example of the system and how it worked in real life. The change selected was identified by No. R01911, "Gimbal Actuators - 3 port versus 4 port." It affected the Orbiter and the Space Shuttle Main Engine and the Solid Rocket Booster which use such actuators. The change was originated in the engineering division at JSC and superceeded a previous change request. The paperwork indicated that this was a mandatory change costing as much as four million dollars during a four year period. Level III Orbiter CCB approved and authorized the forwarding of this change to Level II on August 5, 1975 since the cost was over the $500K limit. The Level II CLRB approved the forwarding of this change to Level I on August 29, 1975, and Level I approval was given on October 16, 1975. The change was, at the same time, undergoing assessment and impact analyses by the cognizant technical organizations so that the change was fully evaluated in terms of cost, schedule, engineering and safety, reliability and quality assurance requirements. It was then reviewed and approved by the Level II PRCB because it affects more than one project as well as being a high-cost item. The directive to implement the change was issued on October 21, 1975 with specific actions to be accomplished by the end of November 1975. At that time an addendum to the original directive was prepared and signed out February 28, 1976. The close out paper shows the actions taken by the appropriate MSFC project offices and contractors. Direction was given to the contractor and

NASA internal documentation was modified accordingly. Project reviews assure that the change was made.

A special effort was made to review the configuration control as applied to the most significant items or elements of the Approach and Landing Test Project. These elements included the test vehicles and supporting GSE, support resources and the operating plans and procedures. Table IX-III succinctly shows the item, control mechanism and the accounting. The activities are divided between JSC, DFRC, KSC, and Rockwell International, Space Division.

4. Configuration Accounting.

The accounting portion of the configuration management system provides visibility to every level of management and working organizations as to the status of the baseline, changes to the baseline and actual hardware configurations and software posture. In addition, almost all of the myriad groups in the Space Shuttle program require such data for safety analyses and assessment, reliability and quality assurance assessment, weights, status reporting, logistics, mission planning, etc.

Configuration accounting activities are divided into two areas: (a) baseline accounting and reporting, and (b) configuration verification and accounting. Item (b) will be discussed separately. Each NASA Center and their contractors utilize different systems to provide the required data. These systems were developed by each organization from their prior programs. Since the necessary data is provided there is no need for uniformity in the system. Because of the focus on ALT and Orbiter, this discussion will

center on Level II at JSC and their support by Rockwell, and the Level III at JSC covering the Orbiter and the 747.

The current system at Program Level II and Orbiter Level III is called the "Baseline Accounting and Reporting System" (BARS). It uses the Rockwell International/Space Division computer system and software. The BARS system has the capability of recording, integrating, statusing, and reporting data for the NASA Levels I, II, and III baseline requirements. Rockwell, as the System Contractor, has personnel located at JSC, MSFC and KSC to perform the required duties. NASA and other element contractors submit on a regular basis to the System Contractor such information as:

a. Level II Change Requests

b. Level II Documentation Changes

c. Engineering Change Proposals (all projects, Level III)

d. NASA CCB and PRCB Directives

e. Level II Change Evaluations

f. Listings of ICD's and specifications, and updates

g. NASA Technical Directives (all projects)

h. Contract Change Authorizations (all projects)

i. Other Closeout Documentation (Level II, III and All Projects)

j. CCB Agenda and Minutes on All Projects

A good deal of this data from the NASA Centers is put into the system through a remote terminal setup at JSC, KSC and MSFC which links them to the Downey Computer Unit.

The output of this BARS setup can be formatted in any form required

by management or the technical organizations. There are, of course, many specifically identified reports produced because they fit a continuing real need by user groups. For example, the baseline documents listing noted before, Level II Change Status Reports each week, PRCB Level II actions status reports each week, and so on.

5. Configuration Verification

Configuration verification is accomplished by Rockwell International Space Division in support of Level II and III program management. They use the data from the individual Prime Contractors as well as the Configuration Accounting System and manufacturing and quality control reporting systems. Thus they are able to provide:

a. Requirements verification used at all major reviews of the hardware and software.

b. Verification of the original baseline configuration and the changes to it.

c. Verification to ensure that the "as built" configuration is compatible with the "as designed" configuration and the "as tested" configuration and that any differences are understood.

In addition to this work, a system level hardware/software verification method is being developed to support the first OFT test, checkout and flight programs.

The PRCB action items are closed by furnishing the Level II PRCB secretary with the following types of documentation to show the PRCB direction has been implemented:

a. Configuration Control Board Directives

b. Contract Change Authorizations

c. Change Orders

d. Supplemental Agreements

e. Technical Directions

f. Directive-Type Memo's or Letters.

When all actions on PRCB directives have been closed, the Level II PRCB secretary will sign a "closeout" block on the directive.

6. Ground Support Equipment Configuration Management

The "station set" concept has been used in managing GSE. A "station set" is an integrated system of GSE units to accomplish a specific function or functions. Functional systems within a station set are identified as "sub-sets." The method of configuration management for these station sets is the same as described for other elements of the Shuttle hardware and software. There is no requirement for traceability on GSE but much of this could be obtained through the current accounting system.

7. Major Ground Test Articles

Test articles required to support such tests as the Ground Vibration Tests, Main Propulsion Tests, and Vibro Acoustic Tests are essentially covered by the same configuration management system described previously. This, of course, is necessary when dealing with items of flight hardware being used in the tests to assure that changes do not adversely effect the hardware.

8. Interface Documents and Their Control

All ICD's have been baselined. There are twenty-one Level II ICD's which cover the interfaces between the major elements of the Shuttle program, e.g., between Orbiter and External Tank, etc.

A list of these is shown in Table IX-IV. This does not include ICD's which interface the Payloads, or the memorandum of understanding that have been developed between such NASA Centers, as JSC/GSFC on communications and computers, and DFRC/JSC on the operation of the ALT program. Interface managers are assigned to each of nine interface areas. They direct the continuing activities, coordinate accomplishment of working group action items and manage preparation and maintenance of the individual ICD's. The top group that oversees all of this is the "System Integration Review" or SIR group at Level II.

9. Shuttle Software Configuration Management

Shuttle software is supplied to the Rockwell International/Space Division as GFE (Government Furnished Equipment). The types are:

a. Vehicle flight software

b. Vehicle ground test software

c. Laboratory software

d. Engineering design aids

e. Laboratory support software

For our purposes, the software follows the path noted below from inception to validation:

Specified By	Coded By	Verified By	Validated By
Rockwell	Rockwell	Rockwell	Shuttle Avionics Integration Laboratory, or SAIL in JSC
NASA	NASA	Vendors	
Vendors	Vendors	IBM-Houston	
IBM-Houston	IBM-Houston	G.E. Co.	
G.E. Co.	G.E. Co.	-	

Given its development cycle and end use software requires configuration management controls similar to the ones for hardware. In summary, the

Shuttle Software Operations Plan and functional directive are being released to provide project-wide common procedures for software similar to hardware procedures and current software is being controlled like hardware through the engineering and quality assurance review system. These items are being followed to completion by the Level II Space Shuttle Configuration Management Panel at JSC.

10. Responses from Program/Project Personnel to Specific Questions.

As a part of its examination of the Shuttle Configuration Management system the task team, during this the first review of this system, posed a series of questions which have been answered by JSC as follows:

Q. What is the situation of the GSE re configuration management?

A. All items of GSE are under strict configuration management after CDR baselining. Any changes other than "make work" must come through the Orbiter change system for approval prior to making the change. Major modifications come back through a CDR and Design Review Board for approval. Orbiter 101 ALT utilizes certain non-GSE items that are required for test and checkout but are below the level of GSE. These are standard tool crib tools, such as wrenches, scopes, etc. plus certain work stands and special test equipment used in manufacturing that have application in the ALT program. The use of these equipments are controlled by the test and checkout procedures which are approved by the NASA. Also, periodic calibration is performed on equipment which requires calibration, again the test and

checkout procedure requires a current calibration on the equipment prior to use in the tests.

Q. The Master Verification Plan and Requirements Documents are many and detailed. When changes are made in the MVP and/or in hardware or software, what concrete methods assure compatibility between these documents, changes, and the test program? How close to flight configuration are the test items used for 1/4-scale testing as well as the MPTA and so on?

A. Shuttle development, as with past programs, is success oriented with regards to development, qualification and acceptance testing. This approach is necessary in order to meet development schedules as well as to prevent excessive costs associated with extension of hardware development schedules which would be required to allow full qualification prior to hardware delivery and installation or qualification. While problems will be encountered, such as the hydraulics problem, which will require rework/redesign, the overall effect of the concurrent development/production is considered cost and schedule effective.

The conditions noted regarding potential failures of hardware causing damage to flight and test hardware due to concurrent development/test of the hardware can and has happened; however, the development data used to confirm design concepts prior to hardware production generally prevent catastrophic failure of the hardware under test. In major tests, such as the MVGVT, MPTA and FRF, the element supplying the test article is required to establish capability of the hardware to survive test conditions at the hardware acceptance

and test readiness reviews. While this cannot assure no failures, particularly where test conditions have not been adequately established, it is expected to greatly decrease risks of any major failures.

The master verification plans (Level II) are used as the basis for each sub-tier (element) verification plan. Deviations/variations to the Level II requirements are negotiated with the element project offices/contractors at the time of approval of the Level III plan. The Level III plans are Type I documentation, requiring NASA CCB/PRCB approval. Detail test requirements for element hardware are reviewed and approved under the umbrella of the Level III verification plan. If the Level II plan/requirements change, this change requires Level II PRCB approval with appropriate direction to the elements for their implementation. Deviation to Level II Master Verification Plans require Level II approval.

Q. GSE Preliminary Design and Critical Design Reviews are conducted on a fairly continuous basis. How does configuration management system keep up with these activities?

A. Approved changes from PDR's/CDR's are transmitted to the contractor(s). For major impact changes, the contractor prepares a Master Change Record (MCR) which is evaluated for ICD impact by a systems integration and ICD group. The MCR then goes to a contractor engineering change board at which time ICD impact is identified. If a change affects an ICD the contractor prepares a Preliminary Interface Revision Notice (PIRN) to change the ICD.

For minor impact changes, engineering orders (EO's) are

prepared to change drawings. The EO's are evaluated for ICD impact by the System Integration and ICD Group. If the affected drawing is identified as one which impacts an ICD per a master matrix, then a PIRN is written.

PIRN's are technically coordinated and submitted into the appropriate Level II or Level III configuration change system.

Q. What is the program posture on application of controls to documents/hardware/software which must be adequate and timely?

A. While the ICD's themselves are Class I documents, during this phase of the Shuttle program the design drawings have not been baselined as Level II or III documents requiring Class I controls. Design changes reflecting ICD requirements are subject to RI/SD program manager's control utilizing the Master Change Record (MCR) system. During Orbiter/Shuttle formal design review, the design is jointly validated to contract requirements, including ICD's, by NASA and RI/SD.

Q. To what degree are test conductors being confronted by "red-lined" drawings?

A. Test conductors functionto procedures (i.e., test and checkout procedures, TCP's) rather than drawings. Test variances, TVAR's, are the primary means of documenting changes after TCP release. Redlining of TCP's during test are incorporated and authorized by TVAR which reflect the required NASA approvals. Minimal redlining of drawings for manufacture/assembly are authorized. Such redlined drawings are impounded by Quality Assurance and verified to subsequently released updated drawings.

Q. For those areas under Class I control, are you running into the age-old problem of making the paper look like the hardware?

A. Make-work design changes during manufacture/assembly/test are strictly controlled by the RI/SD nonconformance system as documented by Standard Operating Procedure Series J-04. In practice, the system requires the implementing paperwork to remain open until the design change (i.e., EO) is released and verified.

Q. What is the situation with GSE controls versus past practices?

A. On the Shuttle program the pendulum was swung to the extreme in the other direction and even items that are normally classified as "factory equipment" are identified and controlled as GSE. All non-GSE items, especially GFE, are identified and controlled at the GSE station set level.

Q. Are there any EO problems and drawing revisions?

A. The only drawings with more than 10 EO's outstanding are structure drawings which are primarily multi-sheet drawings. Engineering Release Operations continuously monitors this requirement and keeps the responsible senior project engineers informed of such items.

Q. Summarize what the Shuttle Configuration Management system provides.

A. The Space Shuttle system:

1. Provides a systematic approach to the definition of the program management, technical and cost baselines.

2. Provides the Space Shuttle Program Manager with the required visibility (in concert with all program/project management representatives) to make decisions that change the program baselines.

3. Insures that all affected program/project elements have reviewed and evaluated the proposed changes to the program baseline.

4. Identifies to program manager the cost, schedule, weight, etc., impacts of such changes.

5. Precludes unauthorized change to the program baseline.

6. Provides visibility of the changing baseline.

7. Provides the mechanism to insure proper communication and implementation of baseline change decisions.

8. Provides a structured approach to program direction.

9. Provides the mechanism for positive verification of the implementation of the program baseline and changes to it.

C. Information Update

A memorandum of agreement is in process to cover the Range Safety System hardware and control documentation, to provide a basis for the orderly processing of changes and the maintenance of configuration control over the commonality hardware delivery dates, allowable temperatures for the system, qualification test requirements and so on. This is being done at MSFC to cover the external tank and the solid rocket booster projects that are under their management.

There is a current effort to assure management that all of the interface areas are being covered by the proper technical and management personnel. As an example the following interfaces which affect the Orbiter are being examined to assure their proper resolution:

1. T-0 umbilical disconnect bending loads
2. Orbiter roll control during vertical mate
3. SRB ignition overpressure measurements
4. OMS pod and payload bay door graphite epoxy water absorption
5. All of the Payload to Orbiter to Ground interfaces
6. Orbiter/ET ice accretion in the umbilical door cavity

TABLE IX-I

The NASA Space Shuttle Baselines

Level I	a.	Program definition
	b.	Program characteristics
	c.	Program interface requirements
	d.	Program verification requirements
Level II	a.	Level I requirements
	b.	System responsibility allocations
	c.	System schedules
	d.	System budget and cost allocations
	e.	Management System requirements
	f.	Information requirements
	g.	System design and performance requirements
	h.	System interface requirements, excluding interfaces to be controlled by a single project office.
	i.	System verification (acceptance, certification) requirements
	j.	Commonality requirements
	k.	Standard design and construction requirements applicable to the total system
	l.	Other applicable allocated requirements
	m.	Training requirements
Level III	a.	Level I and II requirements
	b.	Design and performance requirements
	c.	Interface requirements
	d.	Verification requirements
	e.	Design and construction standards and specifications
	f.	Training requirements
	g.	Design concepts, approaches, and solutions at the appropriate time
	h.	Product configuration descriptions at the appropriate time.

NOTES:
1. Level I documents include Program Directive #1C, the Program Approval Document (PAD), and other applicable Headquarters input.
2. Level II baseline is best described in the Volumes I through XVIII of JSC 07700, "Space Shuttle Level II Program Definition and Requirements."
3. Level III baseline contains specific requirements applicable to a particular project or element of the total system, e.g., Solid Rocket Booster, Orbiter, External Tank, Space Shuttle Main Engine, Launch Support System.

TABLE IX-II

ICD TABLE OF CONTENTS, ICD-2-17001

Part A

Section 1.	Scope (Orbiter/Carrier Aircraft, Ferry)
Section 2.	Applicable Documents
Section 3.	Interface Requirements
3.1	Physical Interfaces (7 sections included here)
3.2	Structural Loads (5 sections included here)
3.3	Environmental Characteristics (3 sections included here)
3.4	Electrical (2 sections included here)
Section 4.	Abbreviations and Acronyms

Part B

Section 1.	Scope (Orbiter/Carrier Aircraft, ALT)
Section 2.	Applicable Documents
Section 3.	Interface Requirements
3.1	Physical Interfaces (13 sections included here)
3.2	Structural Loads (5 sections included here)
3.3	Environmental Characteristics (3 sections included here)
3.4	Electrical (12 sections included here)
Section 4.	Abbreviations and Acronyms

TABLE IV-III

APPROACH AND LANDING TEST CONFIGURATION CONTROL

Controlled Item	Control Mechanism	Configuration Accounting
Orbiter 101 and Rockwell provided ground support equipment	Orbiter manager's CCB meeting at JSC or DFRC, and when necessary delegating such authority to a CCB meeting at DFRC. Expedited changes to be dealt with by ALT Office Representative at DFRC. All changes must pass CCB. The GSE will be handled by Senior KSC person resident at DFRC.	Rockwell/NASA ALT Orbiter team using RI/SD computer system.
Shuttle Carrier Aircraft, aircraft modifications and modification-related special GSE	Shuttle Carrier Aircraft CCB. a. pre-ALT changes through SCA project manager's CCB b. **APD No. 1300, Rev.1 defines the specific functions during ALT.**	Rockwell/NASA ALT Orbiter team using Manual system.
Shuttle Carrier Aircraft, basic aircraft and standard GSE	JSC Aircraft Operations Division	DFRC Maintenance Division, manual system. American Airlines as far as possible.
Mate/demate Device (MDD), Hanger and mission oriented equipment. Also secondary landing site facilities.	KSC Level III and IV CCB's	KSC accounting system
Mission Control Center-JSC, network and data processing facilities	The Data Systems Analysis Directorate at JSC will control through its own CCB.	Data Systems Analysis Directorate in combination with its own system
DFRC Control Room and supporting data rooms. Particularly to test the inert Orbiter/747	DFRC Line management.	DFRC own system Deliver data base to JSC's "Active Orbiter Team"

TABLE IV-III Continued

Special Equipment, e.g., KSC provided ground support equipment, the MSBLS, crew procedures, etc. are handled by the organization directly involved in providing such items. Turn-around support for the Orbiter and Shuttle Carrier Aircraft is under the control of the ALT Test Support Coordination Group.

Controlled Item	Control Mechanism	Configuration Accounting
Documentation such as:		
a. Mission Objectives and Flight Test Requirements	ALT Project Manager's CCB. The costs involved come from Orbiter. This will probably be the same for OFT.	Active Orbiter and 747 Flight Test Teams will do this.
b. Test Specification Requirements Document used for flight test vehicle test and checkout	Orbiter CCB has approval authority on this items.	JSC Program Operations Office
c. Mission Plans and Operational documentation (mission rules, etc.)	ALT Organization and line management review and approval (Flight Operations Division at JSC)	Active Orbiter and SCA Test Teams
d. Flight crew plans (subordinate to items in (c) above.	Crew Procedures Change Board and Line Management review and approval	Flight Operations Directorate, crew and Procedures division
e. Turnaround plans, operations, (management plans and agreements) Checkout procedures, Test and Checkout Procedures, Test Methods)	ALT Organization CCB	ALT Orbiter Ground Team

TABLE IX-IV

SPACE SHUTTLE LEVEL II
INTERFACE CONTROL DOCUMENTS

ICD No.	SUBJECT
2-CD001	Main Propulsion Test Article, Physical
2-CD002	Main Propulsion Test Article, Electrical
2-CD003	Main Propulsion Test Article, Fluid
2-CD004	Ground Vibration Test, Facility
2-0A001	Space Shuttle/VAB at KSC
2-0A002	Space Shuttle/Pad at KSC
2-1A001	Orbiter/Landing Station
2-1A002	Orbiter/Processing Station
2-1A003	Orbiter/Hypergol Station
2-1D003	Orbiter/Secondary Landing Station
2-1D004	Orbiter-Mate-Demate
2-2A001	External Tank/Receive and Checkout
2-2A003	Flight Vehicle/Launch Processing System Complex
2-4A001	Solid Rocket Booster/Receiving and Checkout
2-4A002	Solid Rocket Booster/Retrieval
13M15000	Orbiter/Space Shuttle Main Engine
2-12001	Orbiter/External Tank
2-14001	Orbiter/Solid Rocket Booster
2-24001	External Tank/Solid Rocket Booster
2-17001	Orbiter/Carrier Aircraft
2-00001	Moldlines

SPACE SHUTTLE PROGRAM

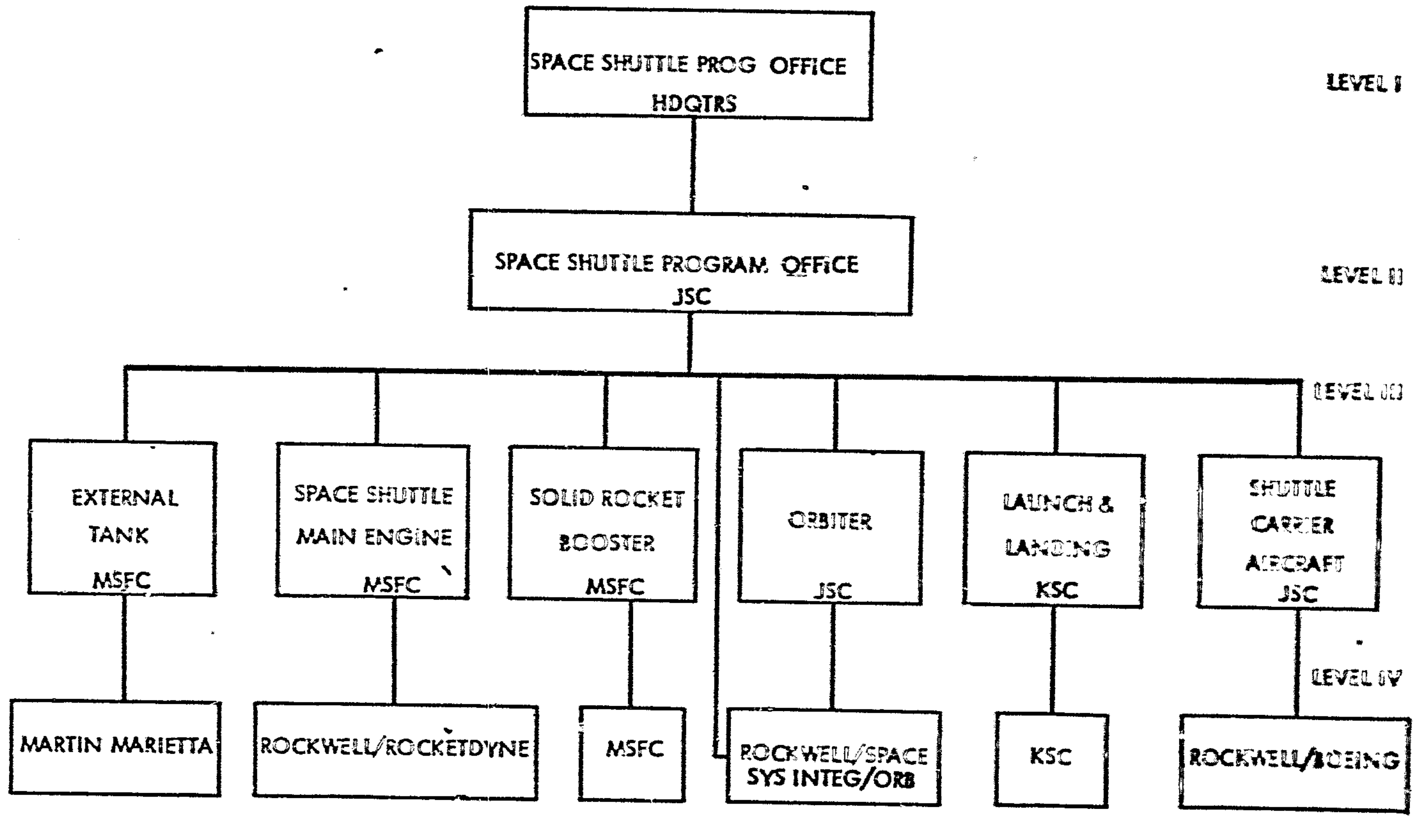


FIGURE IX-1

PRCB/CLRB/CCB STRUCTURE

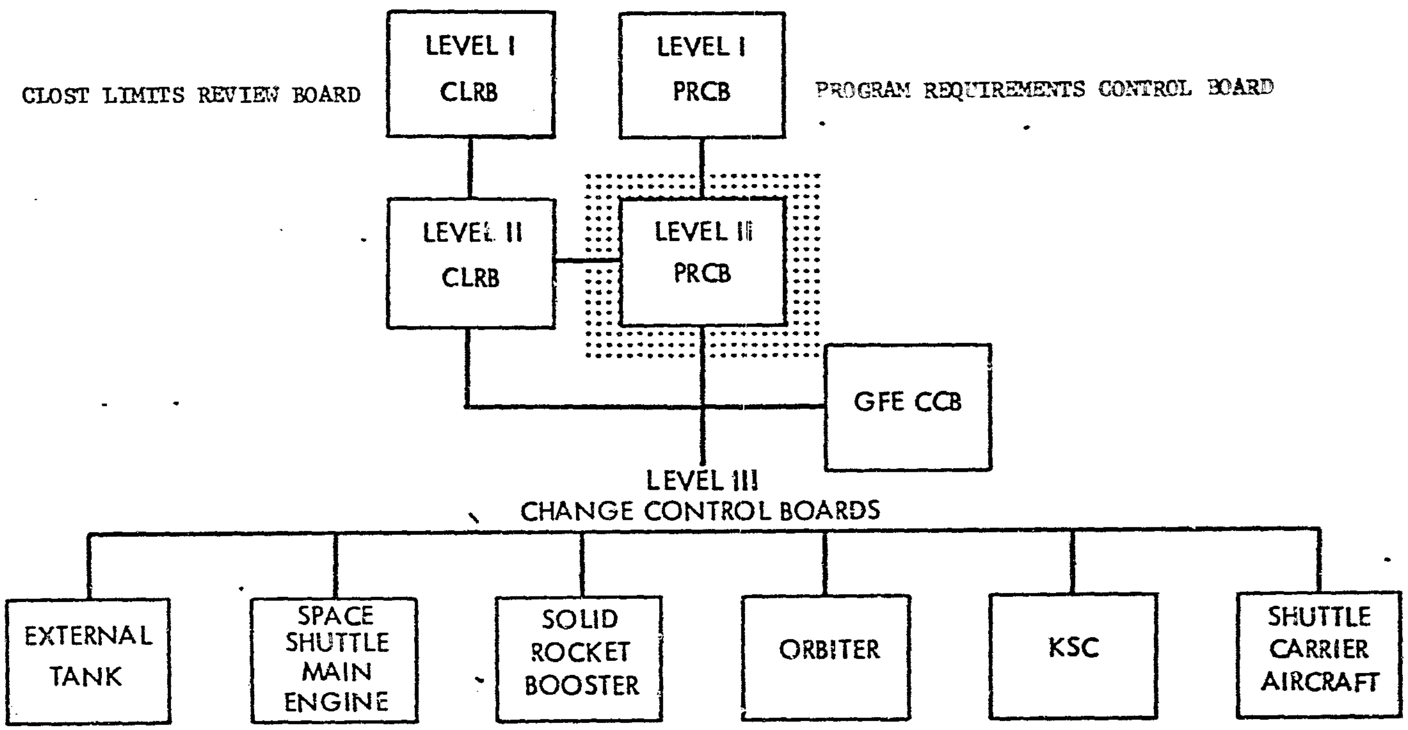
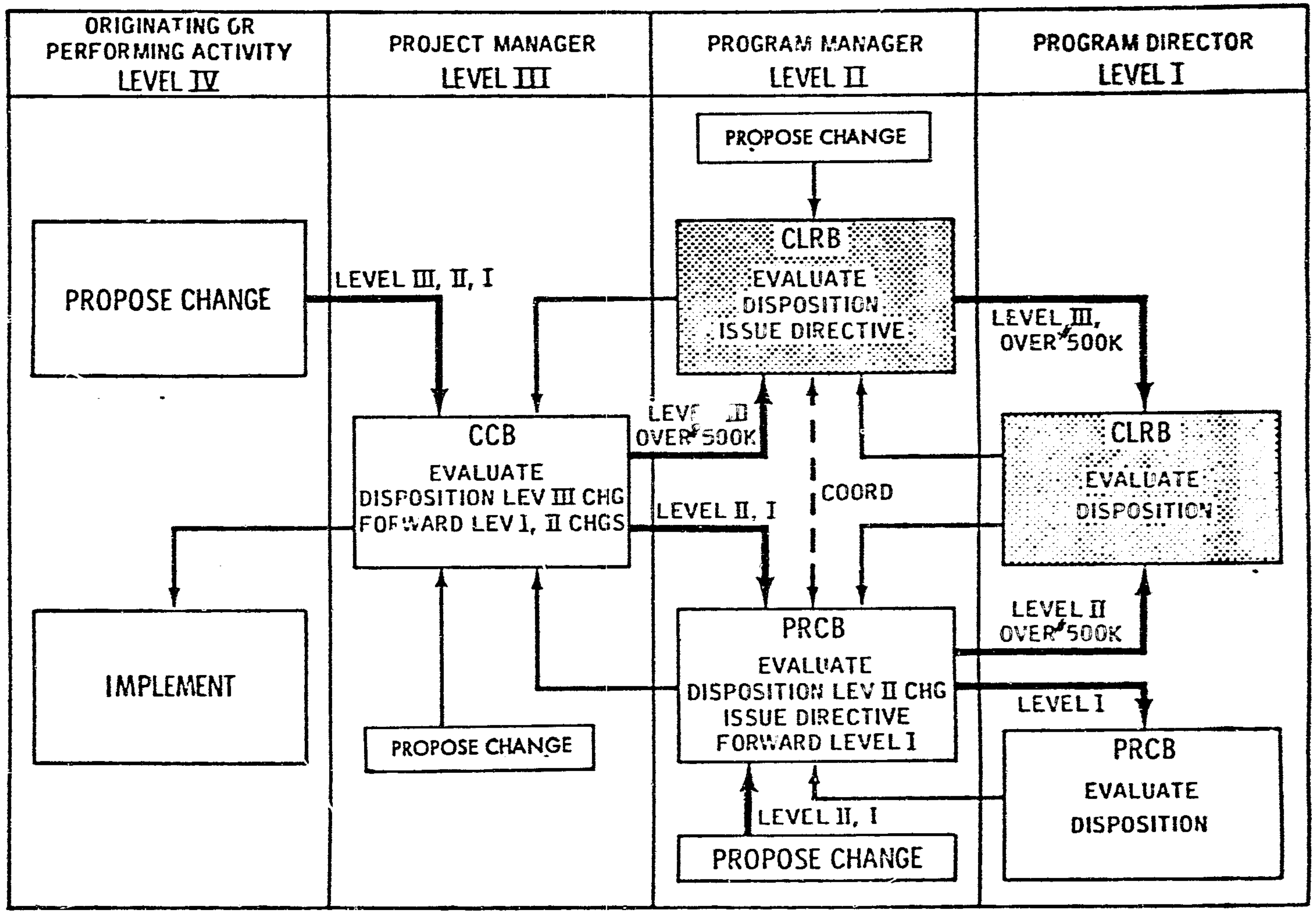


FIGURE IX-2

SPACE SHUTTLE CONFIGURATION MANAGEMENT
CHANGE CONTROL FLOW

FIGURE IX-3



X. ORBITAL FLIGHT TEST PROGRAM

A. Introduction

The orbital flight test program is the last phase in the verification process. It demonstrates the total vehicle capabilities under operational environments. Many aspects of the 102, e.g., aerosurface and hydraulic system development, are also a part of the 101 story and in that respect are covered under Orbiter 101 for the ALT. The Panel is also monitoring those subsystems on Orbiter 102 which would not be proven on the Orbiter 101/ALT flights as well as the major new elements, i.e., Main Engine, External Tank and Solid Rocket Booster.

Later reports will deal more directly with the Orbiter for the first OFT. The purpose of this section is to describe the objectives and the major issues to be investigated through the OFT program so that the following Sections X and XI covering the SSME, ET and SRB are put in the proper context.

B. OFT Objectives

The program objectives are to verify (1) the performance of each of the subsystems across the board, (2) the integrity of the integrated or total vehicle, (3) the operations and checkout procedures, (4) Compatibility of the vehicle with the ground system, (5) the orbiter-to-payload interface, (6) payload handling including deployment and retrieval, and (7) specific capabilities and orbital/sortie maneuvers.

For each phase of the OFT mission there are a number of "issues" that are to be investigated to meet the OFT program objectives. There

are ten phases noted by the program and at least 55 issues within those phases, e.g.,

Phase-Liftoff and boost issues - propellant slosh dynamics
thermal load, external tank
POGO (Stability and Control)

While the Panel does not have the resources to track each issue, the Panel does monitor the handling of the most significant ones. Volume XI "Shuttle Orbital Flight Test Requirements" of the Master Verification Plan series of documents establishes the OFT requirements which must be verified or demonstrated during the Space Shuttle Development Flights.

Because of discussions concerning the appropriate use of the concepts "demonstration" and "verification" in terms of certifying the system, the following definitions are given as found in the "Master Verification Plan-Definitions:"

"Flight Demonstration refers to the verification of the performance of the flight vehicles under a predetermined mix of flight conditions."

"Verification is the process of planning and implementing a program that determines that the Shuttle System meets all design, performance, and safety requirements. The verification process includes certification, development testing, acceptance testing, flight demonstration, pre-flight checkout, and analysis necessary to support the total verification process."

Thus, demonstration is only one facet of the verification process.

C. Risk Assessment

The Panel also monitors the handling of the major safety concerns. The latest issue of the "Major Safety Concerns," JSC 09990 is of sig-

nificance here because it underlines the risks and/or concerns associated with the OFT and ALT test program. These were considered by the Panel in planning the direction the Panel task teams should take in reviewing the SSME, ET, SRB and other unique aspects of the Orbiter and launch/recovery facilities.

For example, the Panel tracks the programs handling of open safety concerns such as the use of the SRB nozzle extension separation ordnance during the first OFT and the ET thermal insulation flammability.

The Panel also monitors the system for abort and contingency planning. The Panel's interests were defined in the Panel's 1976 Annual Report (Vol. I, Page 17-19).

D. Additional Data of Interest

There are numerous factors that must be evaluated and trade-off assessments made for each flight. For example, the ascent segment of the mission required such evaluation of the vehicle loads, thermal stresses, operational techniques, separation techniques, communications coverage, abort plans, range safety, error sources and so on. Flight planning for on-orbit segments include such evaluations of attitude limitation, crew activities requirements, flight test requirements, consumables management and so on. During the de-orbit, entry and landing stages of the mission the same is true of such things as evaluation of energy management, communications, actual systems performance versus predicted and so on.

It is expected that the flights will begin with a crew size of two because of the number of ejection seats (two). The Orbiter, as designed,

can actually be flown by one crewman, so that having two or more adds to the safety of operations. The last two OFT flights will have four crewmen onboard if prior flights indicate that this is a prudent move.

The time between Shuttle OFT launches is approximately 2 to 2 1/2 months with a greater time expected between OFT #1 and #2 and a lesser time between OFT #5 and #6 due to the "learning curve" as experienced on all previous programs.

Current planning shows the following broad information, which can vary with maturity of the program.

- OFT-1 Launch and entry performance under the very best of conditions to optimize for a safe mission.
- OFT-2 On-orbit systems tests. Increased launch and entry loads.
- OFT-3 Remote Manipulator System operation/verification. More detailed thermal testing and again somewhat increased launch loads to further explore the safe capability of the system.
- OFT-4 Further thermal testing, operating payload deployment, and again somewhat high entry loading.
- OFT-5 Work towards proper payloads approach and capture in orbit. Working with increased size crews, and further overall testing to furthedr define results from previous missions.
- OFT-6 Final tests prior to going operational with heavy payloads, off-nominal tests on all systems as applicable, and EVA.

All of these will exercise the KSC Launch and Landing Systems.

E. Orbital Flight Test Design Certification Review (OFT-DCR)

This review is a major program milestone whose purpose is to review and certify that the design meets the OFT requirements as verified by test or analysis, and should have substantiating data that validates that those requirements were actually met. The present date for this review is set for May 1978, but may vary depending upon the degree of completeness of the test programs.

XI. SPACE SHUTTLE MAIN ENGINE

A. Introduction

The SSME Critical Design Review was completed at the end of September 1976 capping a review cycle that commenced in April. The status of the program at that time could be summarized as follows. The potential of the design has been demonstrated and it is an acceptable risk to proceed with the flight engine fabrication. A number of major problems persist and redesigns have been defined where necessary. Flight engine 2004 design has been released. A delta-CDR is scheduled for February 1977 owing to the number of major items to be resolved, e.g., the subsynchronous whirl and turbine cooling problems, the full-scale brazed nozzle. Thus, by the end of February 1977 the following key objectives should be accomplished:

1. Operation of the Space Shuttle Main Engine at Rated Power level (RPL) for long durations, e.g., 60 seconds at RPL as a minimum.

2. Development of the procedures and demonstration of them for use in "start-to-RPL" testing with the 77.5:1 flight-type nozzle.

3. Operation under altitude simulation conditions.

4. Testing of the SSME Heat Exchanger with oxidizer and resolution of the propellant conditioning problems.

The material that follows provides further detail on the results of the CDR and testing program and the status of problems and their resolution.

B. Observations

1. Significant Items From the SSME CDR.

The engine design was critiqued by the following teams: the Engine System Team, the Mechanical and Fluid Systems, Controller Team and the SSME Controls team. The CDR Board, chaired by the SSME Project Manager from MSFC, reviewed the results of these team reviews and concluded that the CDR had been conducted in considerable depth and the results presented with candor. The disposition of all significant RID's was reviewed in detail and approved. The SSME Project accepted the following action assignments in addition to the RID actions:

a. Provide appropriate JSC insight into the Design Verification Specification rebaseline for system related issues.

b. Increase the visibility for MPTA (Main Propulsion Test Article) configuration differences from flight engine requirements.

c. Provide an appropriate review of the closeout actions taken on significant RID's.

The CDR RID's are shown in Table XI-I. There are 45 RID's from the Engine Systems Team, 35 from the Mechanical and Fluid systems, 9 from the Electromechanical Controls group, and 16 from the Controller group. The RID's considered significant are noted in the Table XI-I by an asterisk next to the RID number. The current status of RID action assignments and closeout are shown in Table XI-II.

As for the Main Engine Controller, the baseline unit was originally the P-4 Engine Controller. However, because of numerous

changes based on tests/analyses over the past six months the P-6 controller was considered as the baseline item to be critiqued at this review. This baseline has the following modifications over the P-4 design: the heater set point, POGO related changes, software simplification dealing with the use of dual sensors, power supply changes, uses of dual coils in the electrical system, an asynchronous demodulator, elimination of memory parity errors, variation in the use of the foam used to reduce problems resulting from vibration, elimination of many electrical jumpers and "cuts," changes to history memory, temperature sensor range changes, power supply buss bar connection, Digital Computer Unit no-go timer, etc. The effect of such changes will be determined through a combination test and analysis program. Such qualification requires close attention to be assured that the baseline (P-6) as now accepted is in fact acceptable.

Other major items reviewed, discussed and noted at the CDR include the following:

a. SSME management made a special point of the fact that every individual on the program has the responsibility to make sure nothing falls-through-the-crack by paying attention to everything they do and being aware of the program activities in general.

b. The "long pole in the tent" or major critical objective to be met is the attainment of the specified performance from the turbomachinery.

c. The engines used in the Main Propulsion Tests at NSTL will probably not have all the modifications which apply to flight engines, and the contractor and MSFC will do all they can to keep

these differences to a minimum.

d. The biggest uncertainty in defining the achieved Specific Impulse will be the combustion efficiency, C*. Test results to date indicate that this should be no problem.

e. Temperature and pressure stability conditions at the propellant inlet have been demonstrated in test.

f. The POGO suppression system accumulator no longer utilizes the teflon balls to cover the liquid/gas oxygen interface. Instead a baffle arrangement has been designed to retain the stability of the liquid/gas interface. See Figures XI-1 and XI-2.

g. The improvements that have been made to uprate the engine thrust include the reduction of LPFTP discharge duct pressure loss and increasing the turbomachinery head and efficiency by decreasing the inducer tip clearance and modifying the inducer trim on the LPOTP as well as by under-filing impeller vanes on the HPOTP, by reducing LPFTP clearances and improving seals and under-filing impeller vanes on the HPFTP.

h. Hazard analyses have been completed on the engine heat exchanger for such possibilities as coil leakage, spark igniter "fail-on" and the failure of the limit control for stability and vibration. The FMEA for POGO has been updated and shows six single failure points, for which appropriate solutions have been identified. In addition the traceability system for materials and components has been computerized and is in operation.

i. Changes are being made in the manufacturing process for the flight nozzle to alleviate buckling which resulted during previous brazing operations. Part of this problem resulted from

tubes with uneven wall thicknesses.

2. SSME Project Status

The status of the project as presented here is, of course, like a snapshot in that it shows the engine project as of the date of writing. Progress is continually being made in all areas of the project and this assessment requires updating as tests and analyses are accomplished.

a. NSTL Test Activity

There are two test stands in use: Stand A-1 in which engine 0003 is installed and Stand A-2 in which engine 0002 is installed. 87 tests had been conducted on A-1 and 38 tests on A-2 by the end of the first week of December 1976. Engine 0003 has been run at a sustained thrust level of 75% of RPL. Engine 0002 was operated for the first time for 3.7 seconds on December 3rd in the A-2 altitude simulation (diffuser) facility with the 77.5:1 flight nozzle. In all of the current engine firings several different versions of the high pressure fuel turbo pump are used. These pumps carry modifications which have proved sufficient to cope with the subsynchronous whirl problems and bearing cooling.

The various Engine Controller Units are being used as follows:

BT-1, Engine 0003 on NSTL Stand A-1

PP-1, Software Support at Honeywell
PP-2, Upgraded at Honeywell and now at MSFC Simulation Lab
PP-3, Engine 0002 in NSTL Stand A-2

P-4, Acceptance testing continues

P-5, Completed initial integration testing and acceptance tests continue

b. Engine 0004 Status

There was a weld failure in the main injector during the powerhead proof test. The crack occurred during the second cycle of a five cycle test and extends around the injector portion of the power head. The pressures were about 7700 psi in upper chamber and 5400 psi in lower chamber with ambient external pressure. The electron beam weld that failed was in the lower chamber. The powerhead weld has been repaired and has successfully passed the five cycle test. Further, certain lessons learned regarding such welds and their characteristics should be helpful in supporting not only the SSME welding program but perhaps those of other Shuttle elements. For example, the "nailhead" portion of the weld must not carry high loads (stress/strain).

c. Turbomachinery

The high pressure fuel turbopump (HPFTP) "whirl" problems and bearing cooling problems have been under attack for some time now. The causes of the whirl problem have been identified, solutions determined, stability thresholds predicted, and safe operation demonstrated up to 36,800 rpm. It was concluded that complete redesign was not required. Basic fixes have included increased stiffness, elimination of deadband, decreased "drivers" and added damping. The term "drivers" relates to internal hysteresis, the Alford Effect, interstage seals, non-linearities, deadband. It was determined that the turbine aerodynamic forces were not the principal-type driver. Various combinations of these modifications have been incorporated in the three HPFTP's and have had slightly different degrees of success. Two additional turbopumps are being assembled with additional instru-

mentation and modification to the inboard bearings. These will be tested in the near future and should do even better than the three mentioned above. Deadband is the "play" in a system, or the available motion through which the shaft can move without effective response from adjacent parts. Further testing is in progress on NSTL engines and at in-house laboratories. It is hoped that this problem will be adequately resolved by February 1977 so that the program can meet the schedule for a 60-second Rated Power Level (RPL) firing.

The turbine cooling for the HPFTP has been the subject of much attention at the same time that subsynchronous whirl has been of concern. There have been turbine end bearing failures and hardware cracks resulting from insufficient cooling capacity. The following actions have been taken:

(1) Turbine cooling is to be enhanced by improvements in the high pressure coolant supply, tip seal, and piston ring.

(2) Fuel coolant directed to the turbine end bearing (pre-start flow).

(3) Baffle incorporated in the 2nd stage turbine wheel hub to reduce the pressure loss in the coolant vortex. Tests have confirmed that vortex was the primary cause of turbine end overheating.

(4) The bearing test program will cover the existing bearings, an improved cage bearing and the use of a roller bearing. A better understanding of the cooling circuit can be gained from Figure XI-3.

(5) Procurement of a 45 mm heavy-duty type bearing as a backup unit.

The performance or efficiency of the turbomachinery has, in some cases, been below that required by the design specifications. Depending on the turbopump the efficiency ran between 10% and 15% low and the head between 5% and 15% low.

The low pressure oxygen turbopump (LPOTP) has shown dramatic improvement when the inducer vane and the tip clearances were changed, e.g., vane height increased and tighter clearances. Tests will continue on these modifications and include those involved in POGO suppression. The high pressure oxygen turbopump (HPOTP), although low in head (6%) and low in efficiency (10%) based on COCA-1 tests, appears to be sufficient to meet current engine performance requirements. None the less further actions are being taken with the hope that with increased head, reduced speed improved suction performance can be achieved through underfiling the impeller. The low pressure fuel turbopump (LPFTP) low head problem is being worked through modification of the inducer trim and improvements in the volute design. The high pressure fuel turbopump (HPFTP) besides the "whirl" problem has experienced a 6.5% low head condition at RPL. A number of changes are being made to bring the head and efficiency up to a higher level. It should be emphasized that such performance problems are a normal part of the development cycle for large high performance engines and were experienced on the Saturn F-1 and J-2 engines.

d. Combustion Devices

The Thrust Chamber Assembly has been undergoing a series of "bomb" tests to develop the stability rating. The fourteen detonations were successfully completed and recovery from all disturbances was within 5 milliseconds. The bomb and bomb locations within the main injector of the thrust assembly are shown in Figure XI-4; the thrust chamber pressures based on such tests are shown in Figure XI-5.

The other major item in this subsystem is the 77.5:1 flight nozzle. There have been fabrication problems over the past months because of

the cooling tubes, new thermal design loads and the brazing process. Most of this has now been cleared up and testing of the reworked nozzle is now underway. Nozzle testing at COCA-4B stand at Santa Susana has been successful in terms of characterizing the nozzle heat load, pressure drop and performance as well as the nozzle side loads and transient behavior during ignition and transition to higher and higher power levels. Some of the significant results of this testing are:

(1) The heat load turned out to be about 65% of the calculated value.

(2) The pressure drop was 297 psi versus a calculated 316 psi.

(3) The I_{sp} value was 455.3 seconds. (Calculated)

(4) The side load was about 65% of the design value.

The redesign of the nozzle jacket to cope with latest heat loads provided by the JSC and Rockwell International/Space Division for the flight environment will cost an additional 140 pounds per engine. This redesign is shown schematically in Figure XI-6 and XI-7. The nozzle tube rupture during proof test appeared to be caused by weak spots in the wall thicknesses. The problem was traced back to the tube manufacturer's tube drawing machine, which produced reverse taper in the tubes. Tubes for the three R&D and two MPTA nozzles to be used in development tests will be selected from those currently available. Tubes will be inspected and those which yield a safety factor of 1.4 or higher are to be used. Only the new tapered tubes having a minimum safety factor of 1.5 will be used on the flight nozzles.

e. Controller

The controller hardware and software are beginning to jell. Controller maturity would indicate that the option of a backup unit may never be needed. The BT-1 unit has more than 1200 hours of trouble free service, the PP-3 mounted on engine 0002 has 560 hours, and the PP-2 at the NASA simulator laboratory in MSFC has more than 620 hours. The P-4 controller has been delivered to support the 0004 engine test program, and controller P-5 has been delivered to support the 2001 engine test program, which is the MPTA unit. The other MPTA units designated F-1 and F-2 are presently scheduled for delivery in March and April of 1977. The development verification tests for the improved power supply unit have been successfully completed. The unit included those configuration changes addressed to the P-6 controller, e.g., EMI fixes, power transient mods, vibration fixes, producibility improvements. Another configuration update is being made to the PP-2 controller to bring it up to the P-4 configuration for use in the MSFC sim lab.

Because the P-6 controller is now the flight-type baseline controller and it has some twenty-one changes from prior P-4 controller which was the baseline, it received a Preliminary Design Review (PDR). It will also be reviewed again through a special Critical Design Review at the appropriate stage of testing.

Some of the changes for P-6 are:

(1) New heater set point

(2) Changes related to POGO

(3) Software simplification changes dealing with the use of dual sensors.

(4) Power supply changes (mentioned above).

(5) Use of dual coils in the electrical system.

(6) New asynchronous demodulator.

(7) Deletion of cuts and jumpers.

Software appears to be moving along at a compatible pace with the engine test program and the MPTA and SAIL operations. The software utilization plan which ties engines, controllers and the development program tests to software development schedule is shown in Figure XI-8. A Flight requirements baseline review has been completed and this baseline is under Class I configuration management as a Rocketdyne responsibility with NASA Technical concurrence.

f. Additional Items of Interest

There had been indications that Incoloy 903 which is used in portions of the SSME will have significantly reduced life capability when subjected to hydrogen flow in a form of hydrogen rich steam at 1400° F. Tests conducted by Rocketdyne indicate the same thing. Additional tests are being conducted to gather more data on the physical properties involved and more specific data on life cycle values. The components where Incoloy 903 is used include:

(1)	Hot Gas Manifold Liner	Max. Temp. 1200 to 1400 F.
(2)	HPOTP Turbine Housing	1275
(3)	HPOTP Turbine Inlet Strut	1150
(4)	HPOTP Inner Stage Seal	1000
(5)	HPOTP Exhaust Strut	1000
(6)	HPFTP Bearing Support Seal	875

(7) HPFTP Turbine Support 700

(8) HPFTP Bellows 600

The problem is Low Cycle Fatigue reducing the life expectancy, which is related to environmental and hold-time effects. High Cycle Fatigue is related to the processing and surface effects. Resolution of this concern at elevated running temperatures is expected by the end of January 1977.

Major SSME milestones as seen at this time are shown in Figure XI-9.

C. Information Update

The number of tests conducted on the SSME are quite large since this period and for some months to come, will be devoted to development tests at NSTL on two test stands, and at the Santa Susana sites. The resolution of the turbomachinery whirl and cooling problems require tests to be conducted as often as possible to determine state-of-the-resolution. For instance, at NSTL Stand A-1 four and even five tests a week have been made. Perhaps the major area of concern is the ability of the analysts to reduce the test data and to thoroughly digest and understand what it means before going into the next set of tests. One thing that mitigates this problem is the small steps or incremental method of attacking the problem and this permits smaller pieces of data to be handled at any one time. Tests to date indicate problems are yielding to the engineering attack. The engine 0003 in stand A-1 has been operated at 100% of rated thrust for more than 10 seconds and it has been operated at this level more than two times.

Engine 0004 assembly is proceeding with very few problems and the major remaining work is the installation of harnesses and some fluid lines. This engine is being assembled with dummy fuel pumps which will be changed at the time the engine is received at NSTL.. Full power level operation of this engine is expected to take place in March 1977 with conversion to the MPTA configuration in the following month.

Engine Controller Unit PP-2 has been delivered to MSFC after retrofit and is in process of being integrated into the MSFC Simulation Laboratory. The laboratory has been running simulated engine firings as if it were engine 0003. The Flight-I software is being developed and appears to be on schedule.

A close watch is made on the RID's resulting from the CDR, and as they are closed notification is made to all interested parties. The first status report dated January 11, 1977 showed that seven RID's had been closed (S-21, S-29, S-32, M-1, M-2, M-4, M-10).

RID SUMMARY

TABLE XI-I

Date OCT . [illegible]

Sheet 1 of 8

SSME Critical Design Review

ID No.	Subject	Category	Actionee	Due Date	Notes
-1*	Flanges, External Leakage Detection	D	J. Eaton	11/1/76	Prepare closeout sheet
-2	Pneumatic Assembly, Operational Temperature Range	DR	J. Eaton	11/1/76	Forward to Main Propulsion Panel
-3*	Helium System, Operational Pressure	A-3	J. Eaton	11/1/76	Coordinate helium system requirements
-4	Fuel System, Liquid Air Formation	DR	J. Thomson	1/1/77	Incorporate with DVS baseline
-5*	HEX, Hazards	A-3	O. Morris(JSC) & RKD	1/1/77	RKD support Level II's integration efforts
-6	System, Propellant Feed System	DR	J. Thomson	1/1/77	Incorporate with DVS baseline
-7	Hydraulic System, On Orbit, etc., Thermal Conditioning	DR	J. Thomson	1/1/77	Incorporate with DVS baseline
-8	Hydraulic System, Hydraulic Lockup Verification	DR	J. Thomson	1/1/77	Incorporate with DVS baseline
-9	System, Shutdown Sequence	A-1	RKD	1/1/77	Initiate PIRN defining sequence
-10	System, Injector Dome Purge at Cutoff	A-1	RKD	1/1/77	Define purge requirement
-11	System, Pneumatic Shutdown	A-1	RKD	5/1/77	Demonstrate capability
-12	System, Fuel Insulation	A-1	RKD	4/1/77	Demonstrate design adequacy
-13	System, Operation Subsequent to Hydra/Controller Failure	A-1	RKD	12/1/76	RD to define plan
-14	System, Envelope Verification	A-1	J. Thomson & RKD	1/1/77	Verify envelope against MSFC template
-15*	System, Start Sequence Development	A-1	RKD	12/1/76	RD to define plan
-16	Ducting, Interconnects Gimbal Testing	A-1	RKD	12/1/76	RD to define plan

SSME Critical Design Review

RID No.	Subject	Category	Actionee	Due Date	Notes
S-17	System, Specific Impulse	A-1	RKD	12/1/76	Validate capability
S-18	System, Alignment	A-1	RKD	2/1/77	Validate capability
S-19*	System, Fracture Mechanics Analysis	A-1	RKD	12/1/76	RD to define plan
S-20*	System, Fracture Critical Components (58)	A-1	RKD	12/1/76	RD to define plan
S-21	System, Validation of Casting and Suppliers	A-1	RKD	11/1/76	Submit closeout sheet
S-22	AF Valve/HEX Coil Failure	D	R. Weesner	11/1/76	Submit closeout sheet
S-23	AF Valve Checkout	D	R. Weesner	11/1/76	Submit closeout sheet
S-24*	Bleed Valve Failure Mode	A-1	J. Thomson	11/15/76	Clarify FMECA ground rules
S-25	FMEA, Open Actions on Criticality 1 and 2 Items	A-1	RKD	1/1/77	Submit closeout sheet
S-26	Ducting, Bellows Liner Cracking	A-1	RKD	1/1/77	Define 2004 duct design
S-27	Thrust Chamber, Oscillations	D	J. Smith	11/1/76	Submit closeout sheet
S-28	System, Bleed Flow Post Shutdown or Abort	A-4	O. Morris (JSC)	12/1/76	Define Level II requirement
S-29*	System, Drying Purge	A-4	RKD	12/1/76	Define requirement
S-30	System, Overhaul	D	J. Eaton	11/1/76	Submit closeout sheet
S-31*	System, Water Entry into Engine	A-3	RKD	1/1/77	Define moisture removal technique
S-32	GSE, Thrust Chamber Nozzle Sling	A-1	RKD	11/1/76	Define requirement
S-33	GSE, Engine Handler Locking	A-1	RKD	12/1/76	Revise documentation
S-34	Ducting, Interconnect Design vs Current Engine Balance	A-1	RKD	4/1/77	Release design

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RID SUMMARY

SSME Critical Design Review

Date OCT . [illegible]

Sheet 3 of [illegible]

[illegible]	Subject	Category	Actionee	Due Date	Notes
S-35	Pogo, Screen Attachment	A-1	RKD	2/1/77	Release design
S-36	System, Transient Model Verification	A-1	RKD	12/1/76	Verify model
S-37	Ducting, LPFTP Discharge Duct Gas Trap	A-1	RKD	2/1/77	Submit analyses
S-38	GSE, Closure Material Incompatible with LOX	A-1	RKD	12/1/76	Submit Material Usage Agreement (MUA)
*S-39	Analysis of Lines, Ducts, Brackets, Gimbal	A-1	RKD	12/1/76	RD to define plan
S-40	Ducting, Flex Joint Test Gimbal Angel	DR	J. Thomson	1/1/77	Incorporate with DVS baseline
S-41	GSE, Design not Complete on GSE	A-1	RKD	1/1/77	Release design
*S-42	System, Burst Diaphragm Leakage, - Engine Compartment	A-1	RKD	12/1/76	Submit recommendations
S-43	System, Residual Hazard Rationale	A-1	RKD	12/1/76	Submit required analyses
S-44	System, Open Safety Items	A-1	RKD	12/1/76	Submit required analyses
*S-45	System, Incoloy 903 Fatigue Properties	A-1	RKD	1/1/77	R. to define plan

Date OCT 1 1976

Sheet 4 of [illegible]

RID SUMMARY

SSME Critical Design Review

	Subject	Category	Actionee	Due Date	Notes
1	Main Combustion Chamber Stability Demonstration	A-1	RKD	11/1/76	Submit test results
2	Contamination Blockage of Main Injector Feul Passages	A-1	RKD	11/1/76	Submit closeout sheet
*3	Flt Nozzle Capability Demonstration	A-3	RKD	1/1/77	Submit study results
4	Flt Nozzle Thermal Protection	D	J. Smith	11/1/76	Submit closeout sheet
5*	Heat Exch Capability Demonstration	A-1	RKD	6/1/77	Submit test results
6	Preburner Resistance Discontinuity	A-1	RKD	2/1/77	Submit test results
7	Preburner Stability Demonstration	A-1	RKD	3/1/77	Submit test results
8	HGM Operational Capability	A-1	RKD	3/1/77	Submit test results
9	ASI Injection and Spark Plug Erosion	A-1	RKD	12/1/76	Submit test results
10	Overhaul Cost	D	C. Pinson	11/1/76	Submit closeout sheet
11*	LPOP Veh Duct Internal Bellows Restraints	A-2	RKD	[illegible]	Submit test results
12*	LPOP Flange Non-uniform Loading	A-3	RKD-SD	2/1/77	Submit interface assessment
13*	LPOP Performance Deficiencies	A-1	RKD	1/1/77	Define design solution
14*	HPOTP Lox Starvation Capability	A-4	J. Eaton	11/1/76	Initiate Level II change request
15*	HPOTP Performance Deficiencies	A-1	RKD	2/1/77	Pursue parallel off [illegible] point
16	HPOTP FPL Operation	A-1	RKD	[illegible]	Submit test results
17	HPOTP Turbine Nozzle Life	A-1	RKD	[illegible]	Submit life assessment
18	HPFTP Axial Thrust Balance	A-1	RKD	[illegible]	Define design solution

Date 6C . '77

Sheet 5 of -

RID SUMMARY

SSME Critical Design Review

No.	Subject	Category	Actionee	Due Date	Notes
19	HPFTP Turbine Nozzle Life	A-1	RKD	7/1/77	Submit life assessment
20	HPFTP Performance Deficiencies	A-1	RKD	1/1/77	Define design solution
21	HPFTP Subsynchronous Whirl	A-1	RKD	1/1/77	Define design solution
22	HPFTP Bearing Design	A-1	RKD	4/1/77	Submit test results
23	HPFTP FPL Operation	A-1	RKD	4/1/77	Submit test results
24	HPFTP Turbine Housing Coolant Liner	A-1	RKD	1/1/77	Define design solution
25	HPFTP Turbine Rotor Blade Life	W			No action required
26	HPFTP & HPOTP Fracture Mechanics Flaw Detection	A-1	RKD	12/1/76	RD to define plan
*27	LPFTP Non-uniform Interface Loading	A-3	RKD	2/1/77	Submit interface assessment
*28	LPFTP Performance Deficiencies	A-1	RKD	9/1/77	Submit test results
*29	LPFTP Vehicle Duct Internal Bellows Restraints	A-2	RKD	7/1/77	Submit test results
30	HPFTP Turbine Purge for Water	A-4	RKD	1/1/77	Define purge requirement
31	TCA Functional Characteristics	A-1	RKD	1/1/77	Clarify balance requirements
32	MCC Service Life	A-1	RKD	1/1/77	Submit life analysis
33	Preburner Erosion	A-1	RKD	2/1/77	Submit test results
34	Preburner Delta P	A-1	RKD	2/1/77	Submit test results
35	HPFTP Turbine Tip Seal Erosion	A-1	RKD	1/1/77	Submit test results

Date ______

Sheet ___ of ___

RID SUMMARY

SSME Critical Design Review

	Subject	Category	Actionee	Due Date	Notes
[illegible]	Controller DVT Testing	A-1	RHD	[illegible]	[illegible] thermal cycle test [illegible]
[illegible]	Vibration Testing	A-1	RHD	[illegible]	Define requirement consistent w [illegible]
[illegible]	Intermittent Failure Resolution	A-1	RHD	[illegible]	Define plan
[illegible]	Change Implementation	A-1	R. Morris/ RHD	[illegible]	Define design baseline
[illegible]	Foam-Pack Testing	A-1	RHD	[illegible]	Define requirement consistent with [illegible]
[illegible]	MIB DVS Testing	A-1	RHD	[illegible]	Submit test results
[illegible]	PVD Specifications	A-1	RHD	[illegible]	Submit specification
[illegible]	Convection Cooling	A-1	RHD	[illegible]	Submit study results
[illegible]	Solder Joint Configurations	A-1	RHD	[illegible]	Revise controller documentation
[illegible]	Operational Program Technical Reviews	A-1	BHT	[illegible]	Submit schedule
[illegible]	Development, Management and Configuration Plans for Software	A-1	RHD	[illegible]	Submit Development Plan
[illegible]	Configuration Control of Software	A-1	RHD	[illegible]	Revise [illegible] Management Plan
[illegible]	Software Test Requirements	A-1	RHD	[illegible]	Define specific plan
[illegible]	Fail Operational/Fail Safe	A-3	RHD	[illegible]	Submit study results
[illegible]	Single Point Failures	DR	RHD	[illegible]	Define design baseline
[illegible]	Controller Checkout Requirements Definition for MPTA	DR	[illegible] Keiser	[illegible]	Submit [illegible]

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Date OCT 5 [illegible]

Sheet 7 of [illegible]

RID SUMMARY

SSME Critical Design Review

[illegible]	Subject	Category	Actionee	Due Date	Notes
-1 *	Hydraulic Actuator, Servoswitch & Servovalve Replacement	ER	R. Weesner	11/1/76	Submit closeout sheet
-2 +	Hydraulic System, Mission Duty Cycle Simulation	ER	J. Thomson	[illegible]	Incorporate w/ [illegible] baseline
-3	Hydraulic System, Hydraulic Actuator Hold Mode	D	R. Weesner	11/1/76	Submit closeout sheet
-4	Hydraulic Actuator, Position Control and RVDT Interaction	A-1	RED	12/1/76	Define design solution
-5	Hydraulic Actuator, RVDT Linearity	D	R. Weesner	11/1/76	Submit closeout sheet
[illegible]	Remote Mounted Flight Pressure Sensor	A-1	RED	1/1/77	Submit VCP
[illegible]	Hot Gas Temperature Sensor Design Change	A-1	RED	1/1/77	Define design solution
[illegible]	Hot Gas Temperature Sensor Response Requirement	A-1	RED	11/1/76	Submit study results
[illegible]	Spark Igniter Environment	A-1	RED	12/1/76	Submit test results

, Encl. Sheet of

SSME - CDR Space Shuttle September 27, 1976	REVIEW ITEM DISPOSITION CLOSEOUT		RID No. As appropriate
RID Initiator's Name	RID Initiator's Organization	SSME	CDR Team
	RID I.D. No. and Title		

RID Closeout Instructions

1. Complete heading of RID Closeout Form.

2. Define action taken; i.e.,

Category	Action
A-1	Actionee identify released formal engineering, quality, test, etc., documentation which implements the requested action.
A-2	Actionee identify ECP submitted or contract change authorized to implement the requested action.
A-3	Actionee identify report resulting from requested study or investigation and recommend appropriate action.
A-4	Actionee identify the Level I or II requirement change or deviation request submitted to change system.
D	Actionee document rationale for disapproval.
DR	Actionee document consideration of recommendation. (Note: CDR Board requested these actions be documented, therefore, a Closeout Form is required)

3. Actionee should sign and date Closeout Form and forward to MSFC, SA52, Attention: Mr. Scott Boothman.

4. Contractor signature, for actions not assigned to Rocketdyne, will be obtained by the MSFC SSME Project Office as required.

5. SSME Project Manager's signature completes all necessary RID action.

6. Copy of completed RID Closeout Form will be forwarded to RID Initiator.

	NASA SIGNATURE
Rocketdyne	James R. Thompson, Jr. SSME Project Manager

TABLE XI-II

SSME RID STATUS

RID No.	STATUS
S-21	"System, Validation of Casting and Suppliers" - First article inspection has been performed on all castings procured for Period "A". Period "B" castings will continue to be processed through full Material Review Board for acceptance. CLOSED.
S-29	"Drying Purge" - Requirements for SSME post operational flight and post ferry flight drying purges at all landing locations were provided. CLOSED.
S-32	"GSE-Thrust Chamber Nozzle Sling" - Rocketdyne will provide a sling for single engine use and the Orbiter contractor will ass an adapter to their horizontal installer for on-the-vehicle thrust chamber handling. CLOSED.
M-1	"Combustion Chamber Stability Verification" - Bomb stability rating were completed and a summary of the test results examined. All stability bomb detonation disturbances to the main chamber were damped with 4 milliseconds. CLOSED.
M-2	"Contamination Blockage of Main Injector Fuel Passages" - A change has been made to incorporate screens on the main element feed passages to eliminate contamination of the main combustion chamber baffle sleeves and attached elements. CLOSED.
M-4	"Flight Nozzle Thermal Protection System" - An ECP has been submitted and is in work.
M-10	"Overhaul Costs" - This RID has been eliminated as the deletion of such costs requirements from the CEI specification has been accomplished.
E-1	"Servoswitch and Servovalve Replacement" was assessed and favored the retention of the released design concept. RID not approved.
E-3	"Hydraulic Actuator Hold Mode Operation" capability is to be demonstrated as a part of and ECP and testing. RID not approved.
E-4	"Postion Control and Hydraulic actuator position sensor (RVDT) interaction" modification will eleiminate the effects of channel cross-coupling. CLOSED.
E-5	"RVDT Linearity and Control Precision" has been established through an engineering change using appropriate insulation to make the unit operative in the required thermal environment. RID not approved.

TABLE XI-II Continued

E-7	"Hot Gas Temperature Sensor Design Change" was authorized through an engineering change to decrease response time. CLOSED.
E-8	Recommended a model study to define the hot gas temperature sensor response time required to provide the required degree of engine safety. A study was conducted and the response of 0.3 seconds is sufficient to meet the requirement. CLOSED.
S-22	"Antiflood Valve Failure" position indicator as a part of the start logic or engine shutdown. Recommended action is being taken via an engineering change. RID not approved.
S-23	"Antiflood Valve Checkout" is being covered by a design modification under an engineering change. RID not approved.
CS-001	"Operational Program Technical Reviews" schedules for the requirements baseline and design baseline for both Flight 1 and Flight 2 software have been established and published. CLOSED.
CS-002	"Developmet, Management and Configuration Plans for Software" was released in November 1976. CLOSED.
CX-003	"Controller Checkout Requirements Definition For MPTA". The MPTA Program has not requested or provided budgeting for Command and Data Simulator or Controller Checkout Console equipment to permit checkout of the Controller. Therefore, additional procedures beyond those developed for the Orbiter checkout have not been developed. CLOSED.
CS-004	"Software Test Requirements" documentation has been established and a schedule set up for implementation. CLOSED.

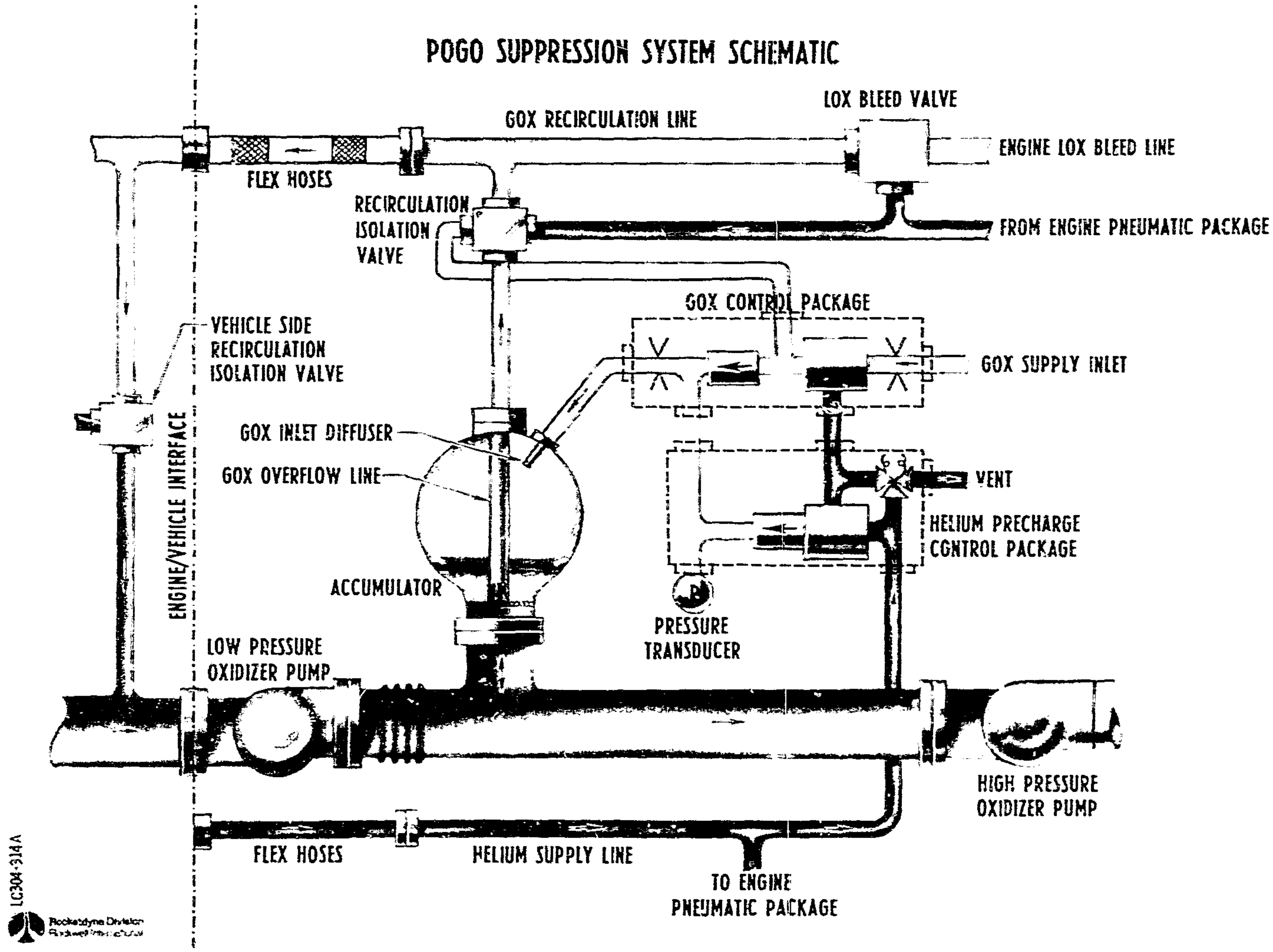
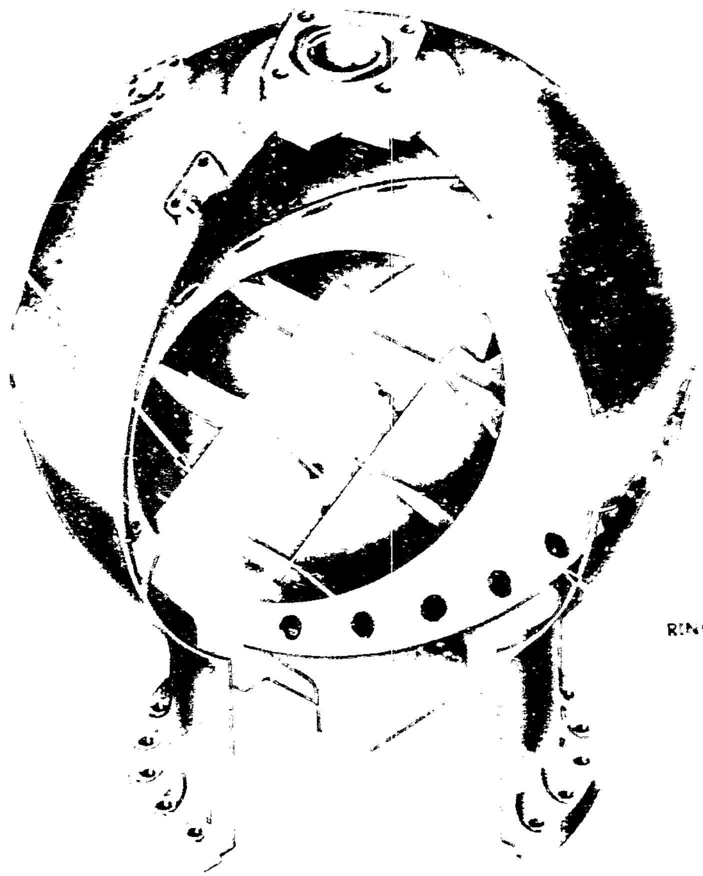

POGO SUPPRESSION SYSTEM SCHEMATIC
LOX BLEED VALVE
GOX RECIRCULATION LINE
ENGINE LOX BLEED LINE
FLEX HOSES
RECIRCULATION ISOLATION VALVE
FROM ENGINE PNEUMATIC PACKAGE
GOX CONTROL PACKAGE
VEHICLE SIDE RECIRCULATION ISOLATION VALVE
GOX SUPPLY INLET
GOX INLET DIFFUSER
GOX OVERFLOW LINE
ENGINE/VEHICLE INTERFACE
VENT
HELIUM PRECHARGE CONTROL PACKAGE
ACCUMULATOR
PRESSURE TRANSDUCER
LOW PRESSURE OXIDIZER PUMP
HIGH PRESSURE OXIDIZER PUMP
FLEX HOSES
HELIUM SUPPLY LINE
TO ENGINE PNEUMATIC PACKAGE
LC304-314A
Rocketdyne Division

FIGURE XI-1

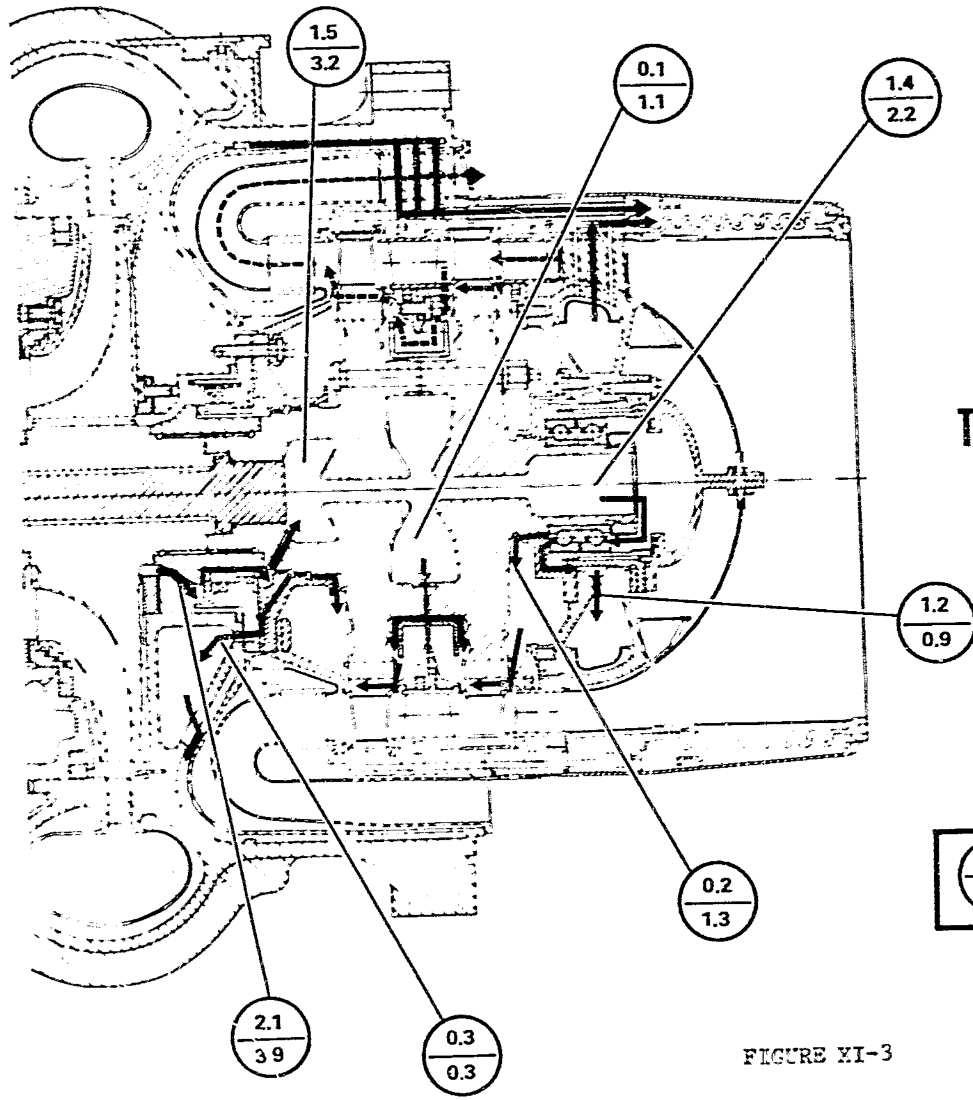
ACCUMULATOR ASSEMBLY



Rockwell International
Rocketdyne Division

FIGURE XI-2

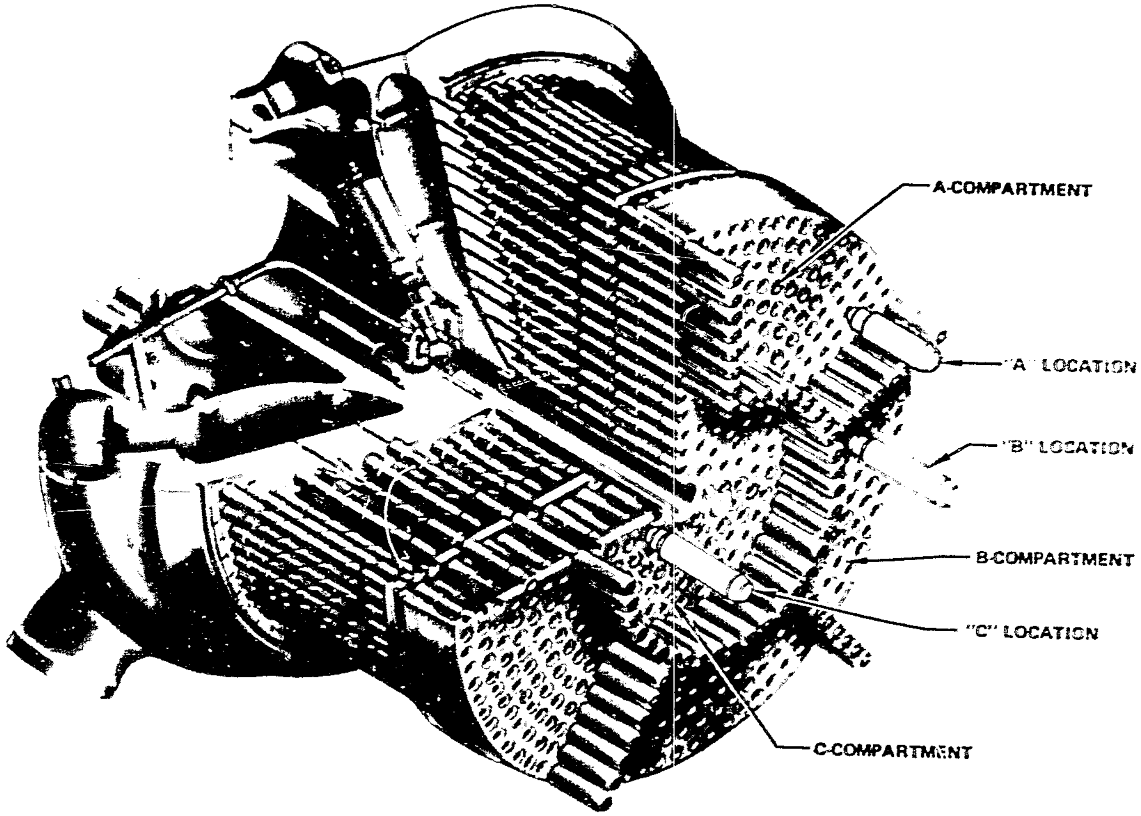
HPFTP
TURBINE COOLANT CIRCUIT
MPL

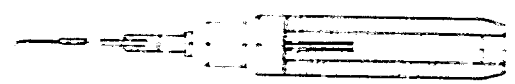


WAS
IS
COOLANT FLOW (LB/SEC)
(AT 30,400 RPM)

FIGURE XI-3

MAIN INJECTOR BOMB LOCATIONS





25 GRAIN BOMB

FIGURE XI-4

THRUST CHAMBER ASSEMBLY STABILITY TESTS
COCA-4B
CHAMBER PRESS/OVER PRESS

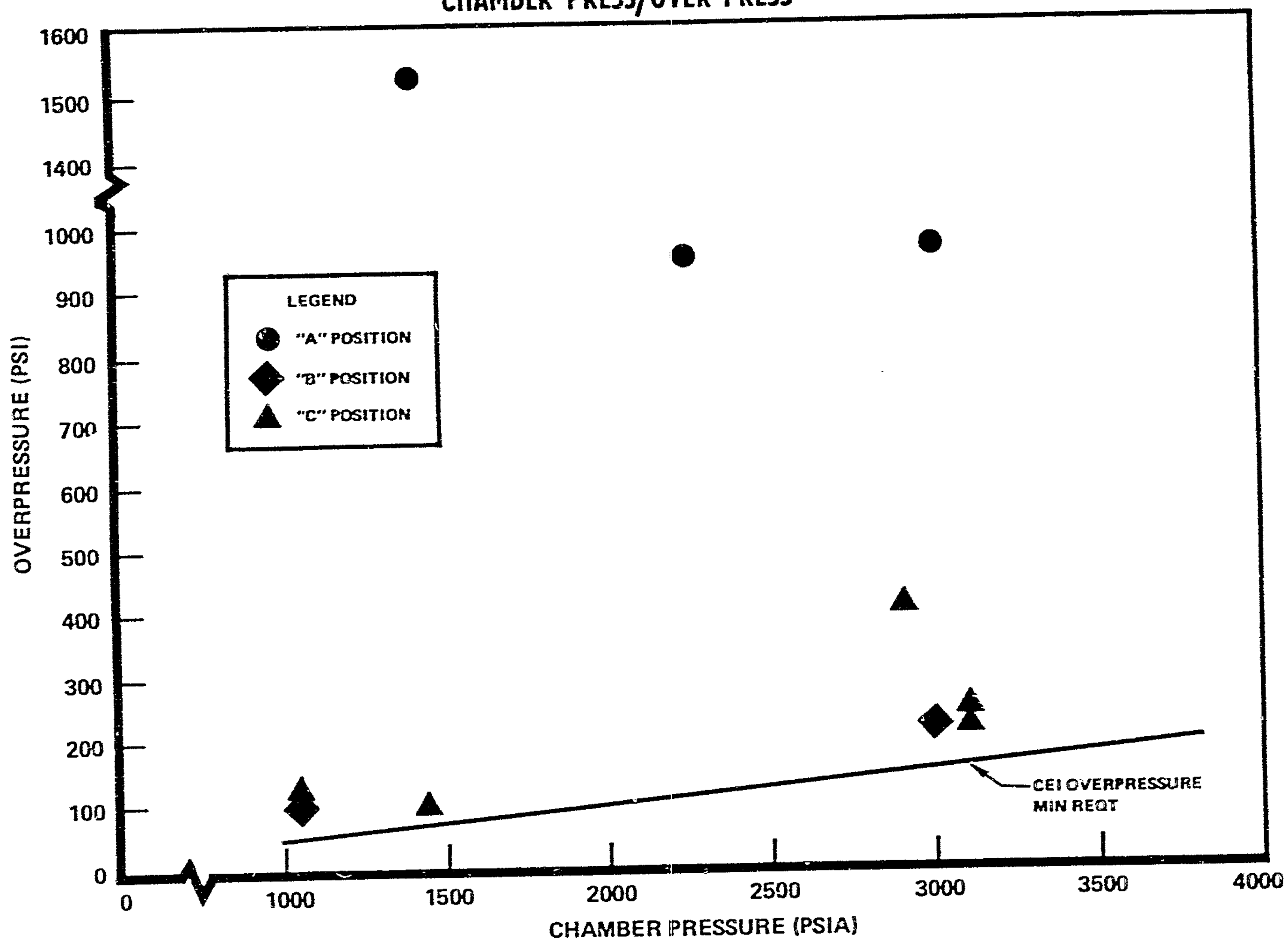


FIGURE XI-5

77.5:1 NOZZLE JACKET REDESIGN PIRN 0034 THERMAL ENVIROMENT

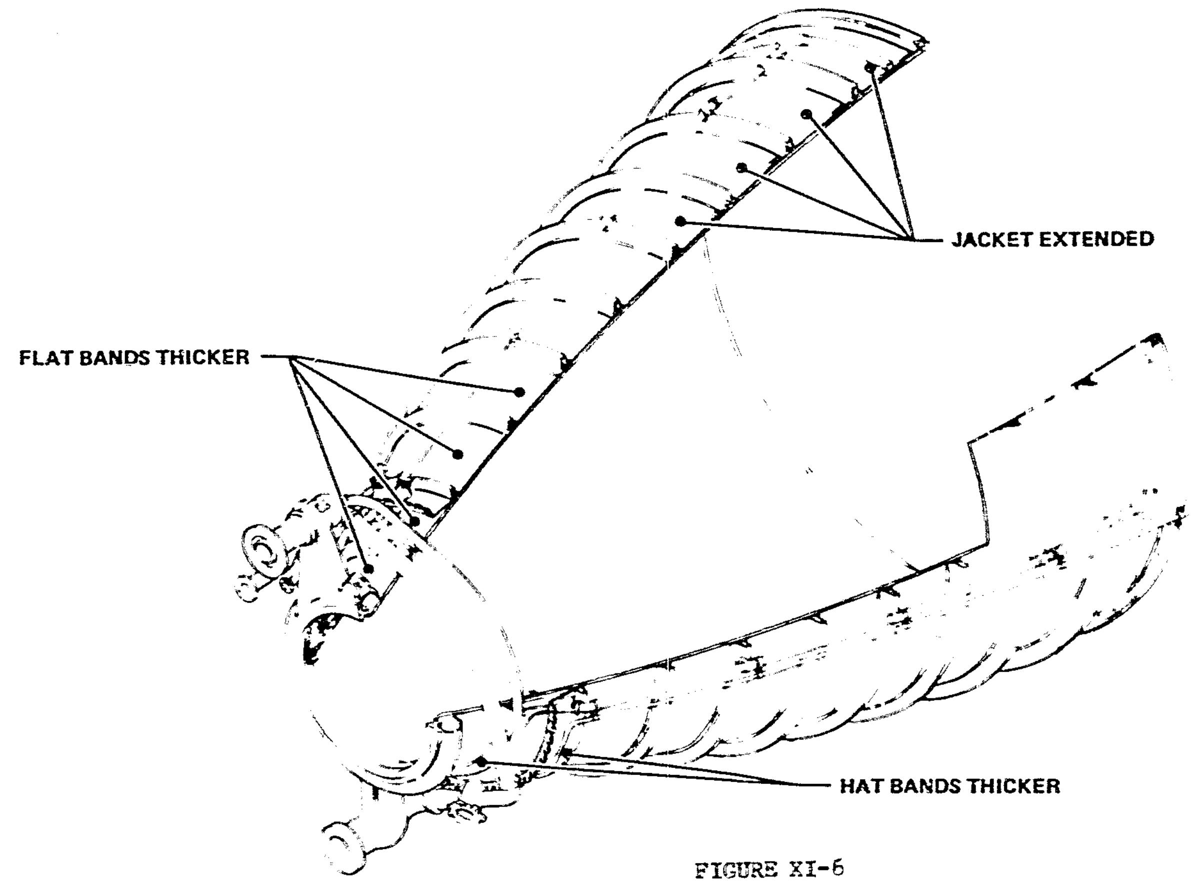


FIGURE XI-6

FLIGHT THERMAL INSULATION

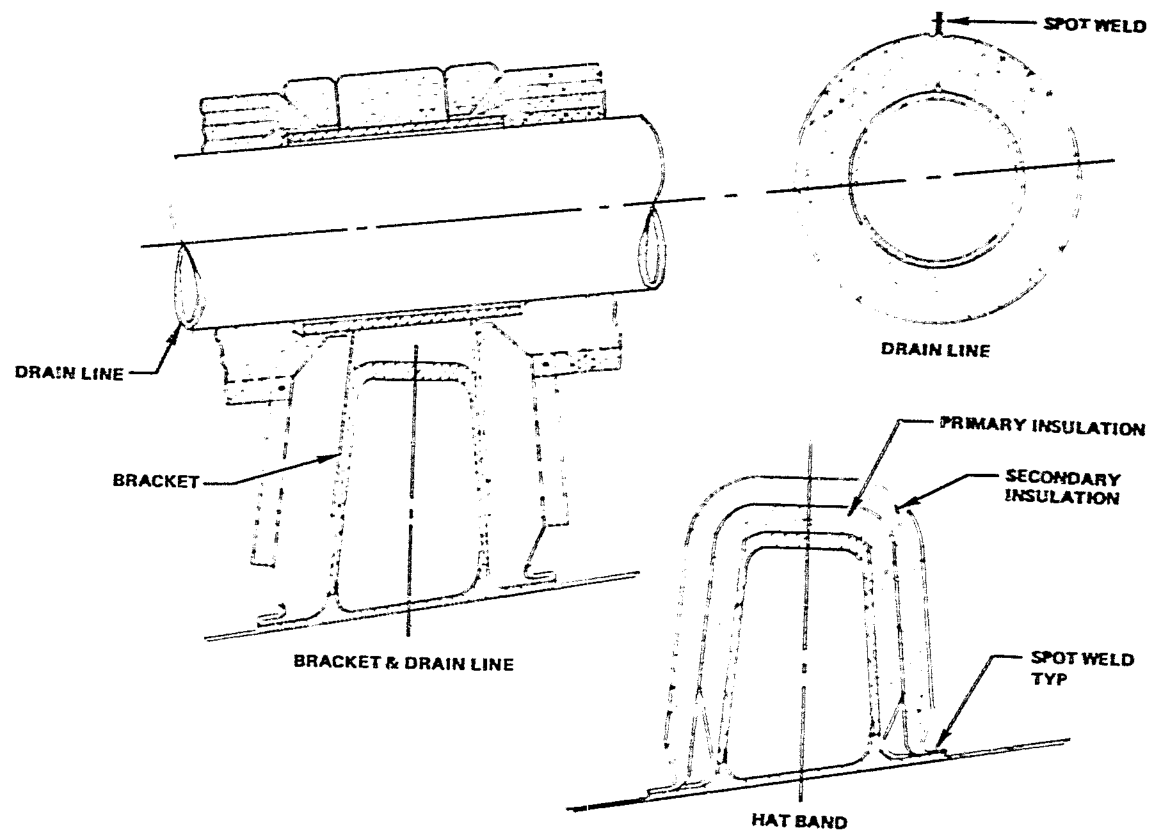


FIGURE XI-7

ENGINE/CONTROLLER/SOFTWARE UTILIZATION PLAN

1 NOVEMBER 1976

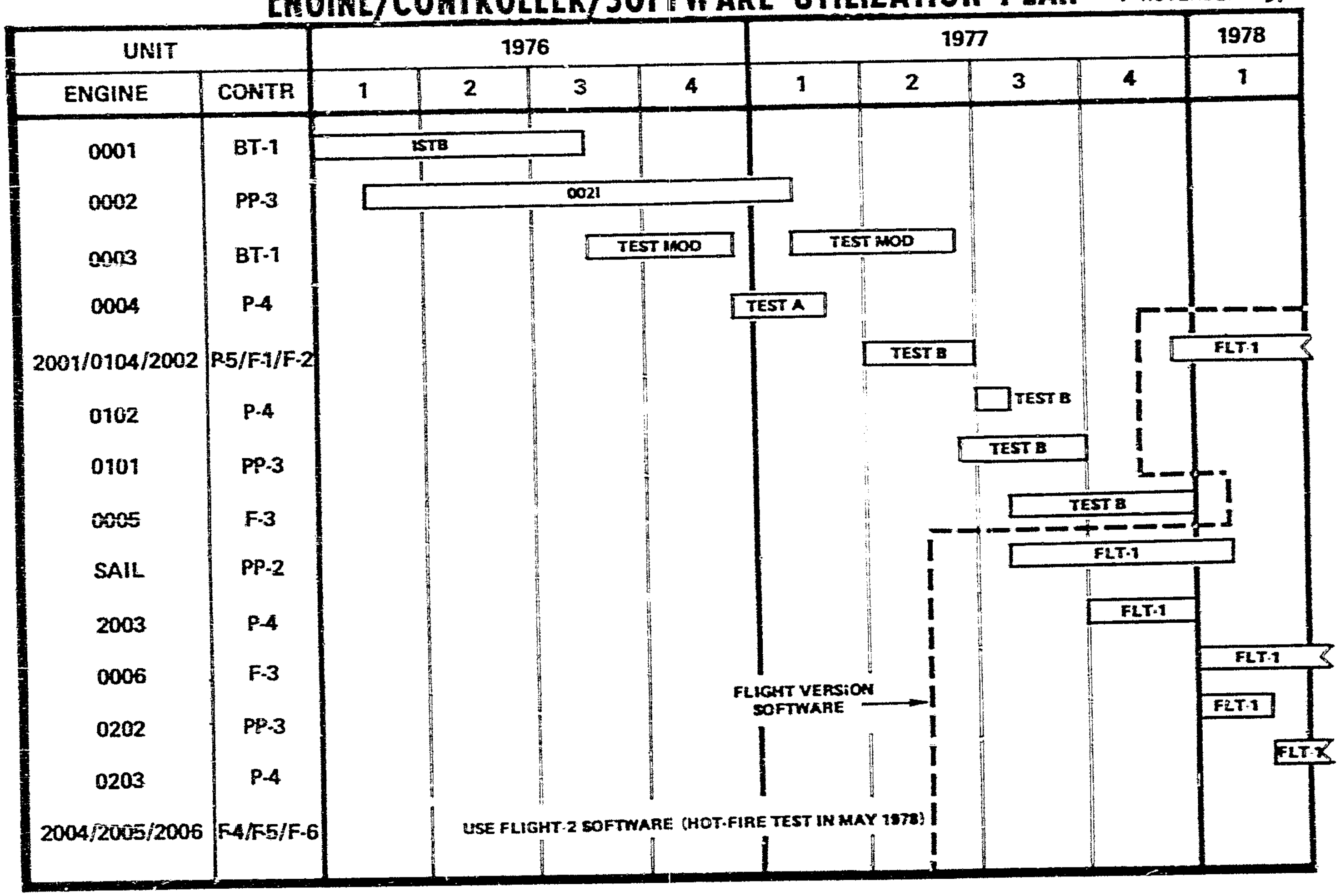


FIGURE XI-8

SSME MAJOR MILESTONES

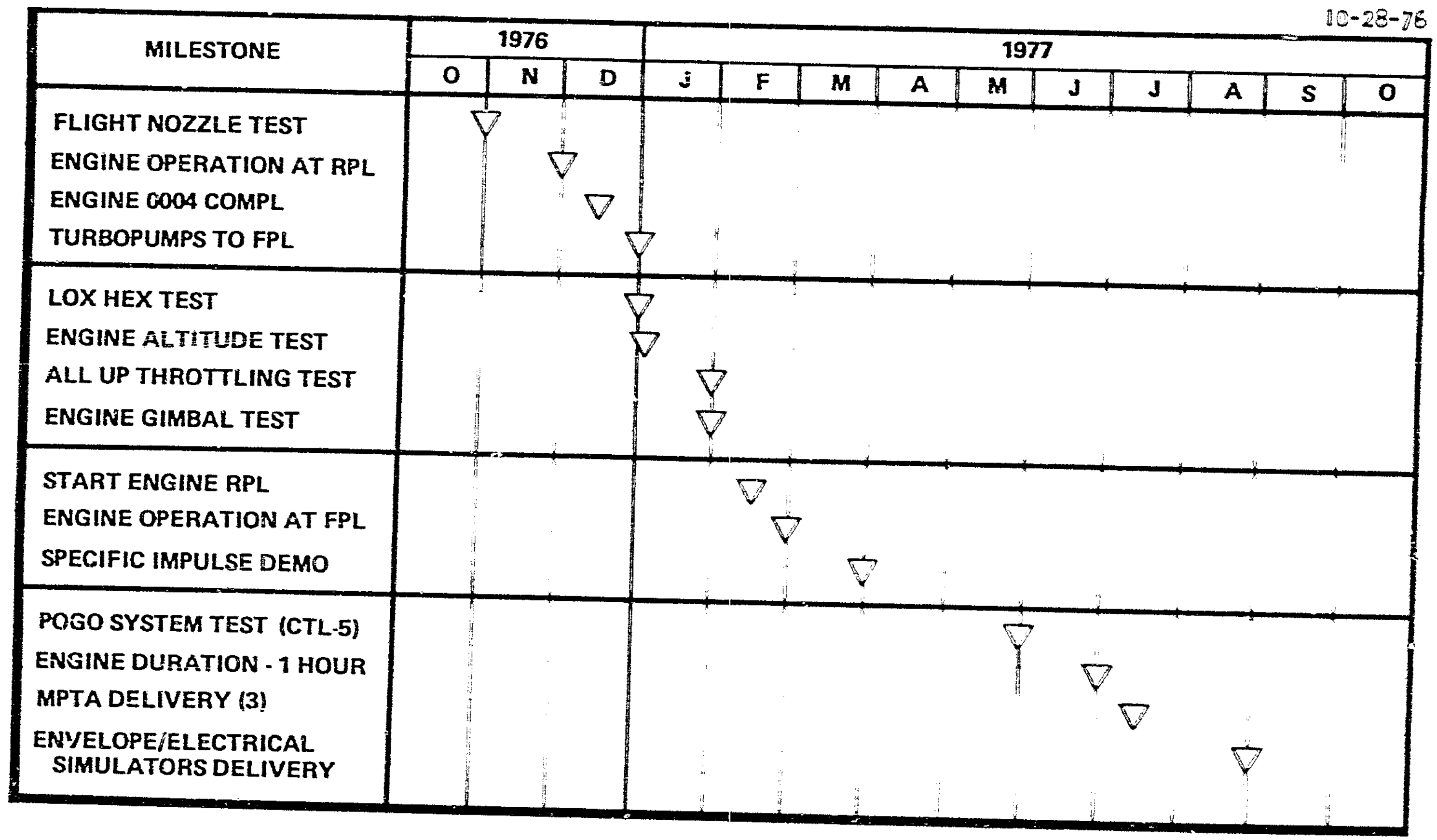


FIGURE XI-9

XII. EXTERNAL TANK AND SOLID ROCKET BOOSTER

A. Introduction

These two elements of the Shuttle system are used only during full operational launch, e.g., they are the major elements, along with the SSME, that propell the system into orbit. In each of these programs the current effort is on the fabrication of hardware to be used in major test programs starting in mid-1977. Production of flight hardware has also been started in certain areas.

A reasonably detailed hazard and risk analysis has been completed for both of these elements and is being updated and expanded as required. In addition hazard analyses have been completed for NSTL facilities and test operations involving the External Tank, the Main Propulsion Test and other associated activities.

B. External Tank

External tank hazard analysis are performed in accordance with the requirements defined in NASA NHB 5300.4 (1D-1) and the procedures in Martin's MMC-ET-RA03. The results of this work is contained in the External Tank Catalog of Hazards. The first part of the catalogue is structured to provide quick reference to each hazard analysis by number, latest revision, date of issue, and hazard description. It also reports the actions taken to eliminate or reduce the risks as well as the further actions planned. In those cases where a significant risk still exists after all appropriate measures have been taken to reduce and control the hazard are categorized as residual hazards. These are identified and explained in Part II of the catalog.

The number of hazards by subsystem at the time this is written looks like this:

Structural and Thermal Protection Subsystem	22 items
Propulsion and Mechanical	31 items
Electrical	13 items
Ground Support Equipment	3 times

There are seven (7) residual hazards noted by the ET program:

1. The ultimate load testing of the Structural Test Article LH_2 Tank and the 10 ft. diameter test tank with liquid hydrogen in them can cause a catastrophic fire if there is a leak for any reason and an ignition source of any type. This testing is to take place at MSFC and the means of containing and controlling this problem are still being worked out.

2. There are a number of so-called "single point failure" fasteners which could lead to the loss of the Shuttle vehicle. Nineteen (19) such fasteners have been identified and these are being handled independently of all other fasteners and will receive 100% proof test and mandatory inspections.

3. Fracture critical welds increase the potential for tank rupture during proof pressure and load tests. Methods are being developed to maintain continuous leak detection to permit test shut-down. In addition provisions are being made to contain explosive decompression if it does occur.

4. Allowable leaks at LH_2 flanges may cause mechanical damage to the thermal insulation increasing the fire potential due to air

liquifaction. Damage to the thermal protection subsystem can lead to structural overheating and possible loss of the external tank dome. Testing to determine the extent of this type problem will not be performed, but seals will receive 100% inspection and so will the flange surfaces prior to seal installation. These then will be completely leak checked. Another added protective process has been to use soft surface coating which seal surface imperfections can impact and minimize seal leakage.

5. External Tank propellants are loaded and off-loaded through the Orbiter. In the event of a leak in the tank, or leak, fire, etc. in the Orbiter, the lack of an independent External Tank propellant drain requires off-loading through the possible hazard zone. This must be kept in mind during KSC operations analyses and requires a thorough integrated ET/Orbiter risk assessment.

6. The reactivity of Titanium with Oxygen. Liquid air formation could occur at those points near LH_2 lines where insulation is not sufficient to preclude it. There appears to be Titanium fittings near such points. This hazard is considered closed based on the direction given to design to preclude air liquifaction and the remote probability of LO_2 leaks with sufficient impact possibilities to cause ignition. Such spark ignition would require a double failure, i.e., an LOX leak accompanied by an electrical failure.

7. Lightning discharge, either natural or triggered by the vehicle, would provide a powerful ignition source for flammable materials on the ET. This is considered manageable because of the protection

C-2

provided by the ground facilities and the existence of an inflight protection system. The inflight system is designed to withstand the effects of a direct strike followed by a restrike during flight. Thus the penetration of an electrical charge into the compartments of the ET are remote.

The Intertank Structural Test Article status is such that its delivery to MSFC is now targeted for March 15, 1977, on schedule. The LOX simulator and the Liquid Hydrogen simulator to be used along with the STA intertank appear to be supporting the STA schedule. Figure XII-I shows these components.

The External Tank Main Propulsion Test Article (MPTA) has had some difficulties in fabrication over the past months. The welding problems for this assembly (Figures XII-2,-3) have delayed the fabrication process by 1 1/2 months. A major problem is obtaining a "round" tank at the welds as well as weld strength with proper safety factors. It appears that the tanks are out-of-round after welding and are then forced into shape creating an undetermined locked-in stress in the weld. More specifically, the status is:

a. LH_2 Tank

The aft dome and aft barrel have been rewelded with heat repairs required to complete the job. The weld inspection which followed identified minor mismatch of the two welded assemblies. This condition, after due study and evaluation has been accepted for use in the MPTA test program. The remaining barrel sections have been successfully welded.

b. LOX Tank

The LOX dome body and frame installation was completed with the machining of the dome chord, which is the interface with the mating flange of the intertank. The assembly of the slosh baffles were completed. The aft ogive assembly has been welded and inspected and hear repairs were required. The forward ogive assembly heat repairs have been made and accepted and this component of the LOX tank is in process of being welded to the aft ogive.

A number of actions are being taken to complete the MPTA tank sections and have the entire external tank available in time to support the MPTA test schedule by such means as selected Sunday work. There will be a continued in-depth review of the operations at each major tool prior to first usage to assure proper results and minimize physical interferences.

The External Tank weight at this time is somewhat over the control weight. Inert Control Weight (Level III) is about 73,300 pounds while the Inert weight (88% calculated, 12% estimated) is about 73,900 pounds. If you add to this the new weight from changes (about 500 pounds) and the normal expected weight growth over the next year there is a weight problem to be resolved.

There are many differences between the flight tanks and the MPTA test tanks. Most of these are to support the special test program requirements such as ground safety requirements. Examples of these differences are:

1. In the vent/relief system an auxiliary common vent mani-

fold has been added on the LOX tank for MPTA along with an auxiliary valve and line in the Liquid Hydrogen tank.

2. Additional Intertank access door panels have been added to the MPTA.

3. An auxiliary propulsion drain has been added in the MPTA manhole covers on both tanks.

4. The tumble system is not on the MPTA unit.

5. There is to be special instrumentation on MPTA.

A major area of concern on the TPS from an operational standpoint is the insulation material properties when heated or subjected to LOX and water environments. The differences between the MPTA and the flight types:

TPS Location	MPTA-Material	ET-1, Material
LOX Tank	BX 250	CPR 488
Intertank	BX 250	CPR 488
LH_2 Tank	CPR 488	CPR 488
Ablator Components	21 square feet of BX 250	1630 square feet of CPR 488

The choice of a material to provide external insulation on the tank has been a complex and difficult one because of the demanding thermal requirements as well as the requirements for producibility. This evaluative process continues and thus the types of insulation noted above for the MPTA and the ET-1 (flight) units may change in the future. At the time this is written:

1. BX-250 is now being tested for material characterization.

2. CPR 488 was selected over the CPR 421 material for use on the LOX tak for ET-1 because of its better toxic outgassing properties.

3. The development of light weight ice protection designs for many local protuberances on the External Tank continue to be a major design concern. The original approach left some areas susceptible to icing. Some of the ice prevention and reduction techniques under consideration are shown in Figures XII-4 and -5.

4. The development of alternate insulated wire designs for use in the LOX tank ullage zone is continuing. This wiring is expected to be subjected to an environment of temperatures up to 500°F and pressures up to 44 psia. A number of alterations have been investigated and a decision on this area should be forthcoming within a short time.

C. Solid Rocket Booster (SRB)

NASA has selected the United Space Boosters, Inc. (USBI) of Sunnyvale, California, a subsidiary of United Technology Corporation, as the assembly contractor for the Space Shuttle Solid Rocket Booster. The scope of work covers all the necessary activities at MSFC and KSC. This is the last major contract on the SRB, and thus takes MSFC out of the direct role of SRB integrator and assembler which has been their role up to now. However, MSFC still retains some integration responsibilities through the DDT&E flights. Basically, though, they will now manage the SRB elements as they have been doing on the SSME and ET portions of the program.

The following observations are based on Panel fact-finding and the SRB Critical Design Review conducted December 8, 1976 at MSFC. The SRB CDR was well organized and the work leading up to the CDR Board meeting appeared to be quite thorough. The total number of Review Item Discrepancy's (RID's) received were 799 ofwhich 614 were approved for action of some type.

A number of items such as these were to be completed in early 1977:

1. A study to evaluate the acoustic emission and x-ray fluorescent techniques is planned during the DDT&E phase to determine the propellant burn rates of the SRM.

2. Transducers have been one of the most replaced components on past NASA programs and the requirment for redundant and must be inspected and leak checked where possible.

3. There appears to be a thermal environment problem with the SRM nozzle outer boot in terms of protecting the flexible seal and the flexible seal to fixed housing joint. Studies of this are being accomplished by NASA and the contractor.

4. Plans should be baselined shortly for integrated testing of the SRM flexible bearing and the SRB Thrust Vector Control system at Thiokol as well as for the development firing of SRM's.

Based on the Task Team visit,the Wasatch Division of Thiokol Corporation appears to be staffed by experience, motivated and creative personnel at all levels. This also is the case for the NASA Resident Office located on-site. It was noted that the contractor

has given the SRM project "individual status," something accorded to major programs at Thiokol.

To date over 250,000,000 pounds of the propellant used in the SRM has been produced for Minuteman Missile motors and others. The changes in the formulation are in the quantity of iron oxide used to control the burning rate. Minuteman used no iron oxide and the Poseidon uses 0.4%, while the Shuttle SRM uses 0.07%. The higher the percentage of iron oxides the higher the burning rate in terms of pounds per minute. The propellant is not adversely affected by its storage or aging. Thiokol had some 40,000 pounds held in storage for over 13 years and it met all specifications when used. There is, then, an extensive experience base as well as fully characterized materials and processes.

Batch mixing is used to produce the propellant since the so-called "continuous mixing process" has never worked out. Six hundred gallon batches (7000 pounds) are mixed at a time in each of three mixers so that there can be continuous pouring of the SRM segments. This is the equivalent of truely continuous casting.

The antioxidant currently used in the SRM polymer is PBNA supplied by Goodrich Chemical Company. Unfortunately they have ceased production so the following alternatives are being investigated. Modify the manufacturing process at Goodrich and the American Synthetic Rubber Company so that they would resume production; find and qualify a new source; or find and qualify a new antioxidant. Thiokol has prepared a plan to qualify an alternate material to replace PBNA by June 1977.

There is sufficient polymer for DM-1 and 2 already on hand and the polymer for DM-3 is on hand but not yet processed by American Synthetic Rubber. The SRM is expected to operate as required from the point of view of thrust capability. The calculated and specified time-thrust curves are shown in Figure XII-6.

The work of the SRB Fracture Control Board continues to assure that attention is focused on minimizing any detrimental effects of stress corrosion and material fractures from material imperfections. Some of the interesting material developed through this board include:

1. Fracture Control Plans for the case, nozzle and ignition system are in the process of review for publication.

2. The SRB Thrust Vector Control Hydraulic Reservoir contains approximately 35 gallons of fluid at 3,000 psi on the high side and approximately 60 psi on the low side. The factors of safety are 1.5 on proof and 2.5 on burst for both operating pressures. The reservoir is being supplied by Arkwin, who also supplies the Orbiter reservoir. The first development unit was completed in November 1976. All pressure vessels are under "fracture control." The remaining question is whether there is a fracture control plan and a requirement for supporting analysis and test?

3. Problems exist with the making of thick butt welds which has triggered an examination of this area and the methods to be used to eliminate unacceptable weldments.

D. <u>Information Update</u>

1. Solid Rocket Booster

As with any rapidly moving program the status of accomplishments and concerns also changes. The material contained here provides more specifics on items already discussed as well as items not previously covered.

Key milestones to look forward to in this SRB Project include the following:

a. The first development firing test of an SRM is scheduled for the June 1977 period,

b. The so-called "Allup" Electrical & Instrumentation Verification Test" (EIVT) is scheduled for sometime in the March 1977 period,

c. An important sub-system delivery Integrated Electronics Assembly (IEA) is scheduled for March which will be a part of the EIVT,

d. Prototype parachutes for the recovery sub-system scheduled for April, and

e. The next months should see a great deal of activity in qualification testing of components for this project.

An examination of the project, e.g., the Critical Design Review and Quarterly Reviews indicate that the Solid Rocket Booster is progressing very well and that the concerns and problems are being resolved in an orderly and comprehensive manner. Special efforts are being made in the following areas which are considered as some-

what troublesome:

a. Project Integration

1. Ascent thermal environment and its impact on the SRB design and performance.

2. The thermal curtain protection for the SRB aft end regarding curtain overpressure and flutter.

3. Qualification of SRB Range Safety components to vibration levels experienced by the External Tank.

b. Thrust Vector Controls rely on the APU which has been experiencing fuel pump performance degradation. The actuators have been reviewed to assure that the design is adequate and there is some consideration being given to the modification of the seals.

c. Major Ground Tests requires the on-time delivery of the support test equipment (STE) for testing structures components and the EIVT and SRB/ET separation test articles.

Solid Rocket Booster lightning protection from direct strikes and from indirect effects continues to receive attention. In addition to NASA and its major contractors on the SRB project support is being received from the Mission Research Corporation and the Lightning Transients and Research Institute. Figure XII-7 represents possible entry points and paths for lightning strikes on the Shuttle System. The direct effects, that is the burning, blasting and direct coupling of voltages caused by lightning arc attachment, include SRM case burnthrough, range safety antenna damage, thermal protection system

damage, frustum separation ordnance initiation, current path off the SRB to other elements and to the atmosphere. Actions are being taken in all of these cases including tests, analysis and combined investigations. The indirect effects, that is the damage or malfunctions due to currents and voltages caused by electromagnetic fields associated with the lightning, are being examined to determine the threat level (threshold value at which damage or malfunction can occur), the circuit susceptibility to the threat level and what should be done to design for achievement of threat levels below the susceptibility values. Analysis, tests and investigations are in progress to determine the threat levels and means of preventing damage by shielding. These resolutions should be reached by mid-summer 1977.

The latest Thermal Protection Subsystem pattern for the SRB is shown in Figure XII-8 which also includes the design limit temperature and maximum heating rates expected in BTU/ft^2-sec.

The following data updates the Solid Rocket Motor material. Among the many significant accomplishments during the past months has been the delivery of the first case segment in September, the completed nozzle bearing test on a prototype system, the delivery of all the development motor (DM-1) case segments by November 1976 and the DM-1 is now in the manufacturing cycle. The SRM nozzle assembly is a major design effort and considered one of the more difficult items to achieve the requirement objectives. Figures XII-9, -10 show this nozzle in cross-section. The redesign is completed and is more

conservative using:

a. carbon cloth phenolic cowl

b. boot thickened to 2.0 inches of asbestos silica filled NBR

c. silica ring added under the fixed housing insulation on DM-1

d. grease added to the boot cavity

e. additional sensitivity analysis to be conducted

f. boot instrumentation increased for DM-1.

The APU Critical Design Review was held at Sundstrand during the second week of January 1977 with the most significant problem surfaced being the degradation in fuel pump performance due to bearing swelling. Various bearing configurations are being evaluated to resolve this problem. Information on these type of commonality items should, of course, be transmitted to all Shuttle elements affected by the use of the APU.

2. External Tank

The ET contractor is completing their assessment of the impact of the vibroacoustic and air-load increases and it would appear that not only will the main propulsion lines for liquid oxygen and liquid hydrogen be affected, but there may be some impact on various other structural items within the tanks themselves. These environmental conditions (increased temperature and aerodynamic pressure or loads) have been under study for some time and the Panel intends to follow the results of impact studies currently underway.

Wind tunnel testing recently indicates that heating rates in the range of 45 BTU/Ft^2-sec may exceed the capability of the SLA 561 ablator currently assigned to protect protuberances, e.g., struts and external fittings.

The Anti-Geyser system design is receiving additional attention to assure that the system can be certified that it meet requirements. Two configurations are under evaluation, these are shown in Figure XII-11. This may lead to a reduction the complexity and weight of the anti-geysering system.

Non-destructive methods capable of inspecting the installed thermal insulation as to its bond-to-surface integrity is receiving continuing attention. The inspection problem on the external tank can also be found on the SRB and the Orbiter. The external tank contractor in working with many methods indicates that at this time the "sonic impedence" method is most promising. Further development and testing will be necessary.

INTERTANK STRUCTURAL TEST ARTICLE

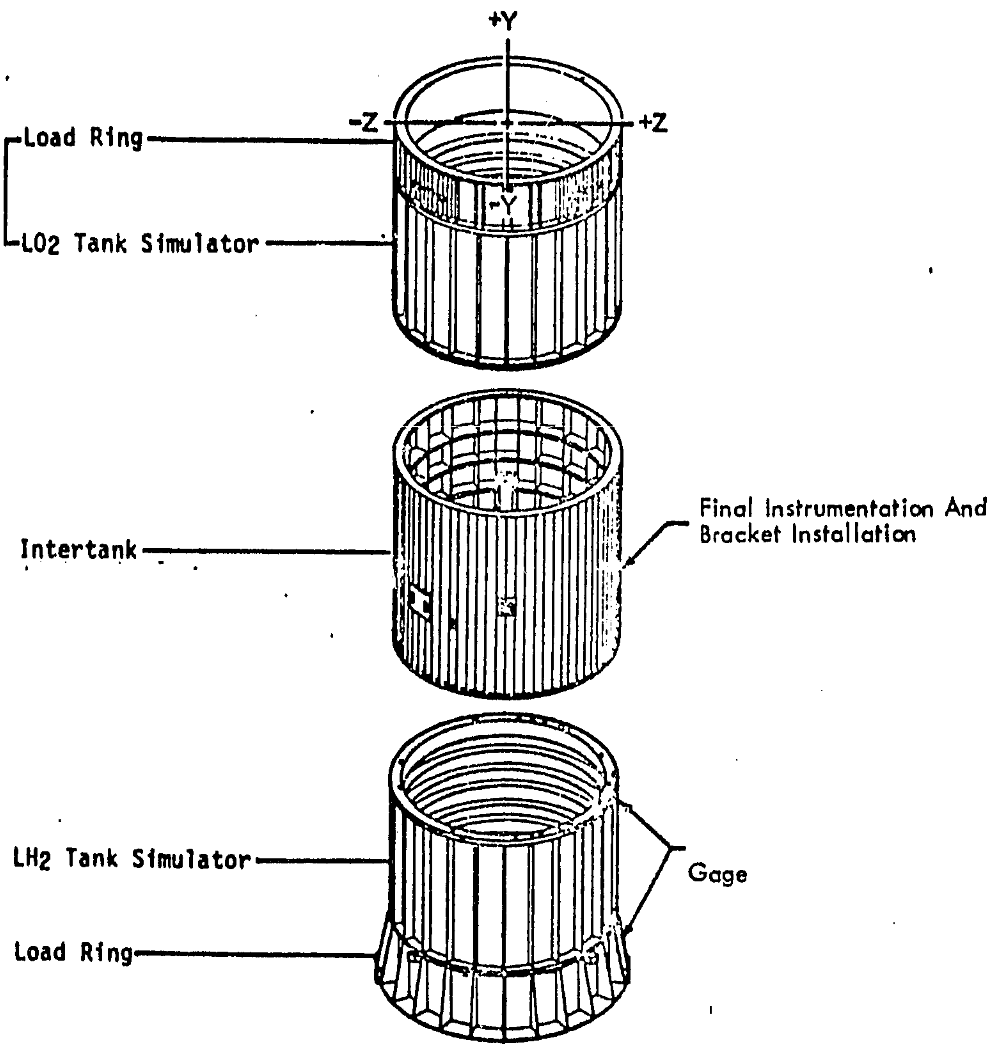


FIGURE XII-1

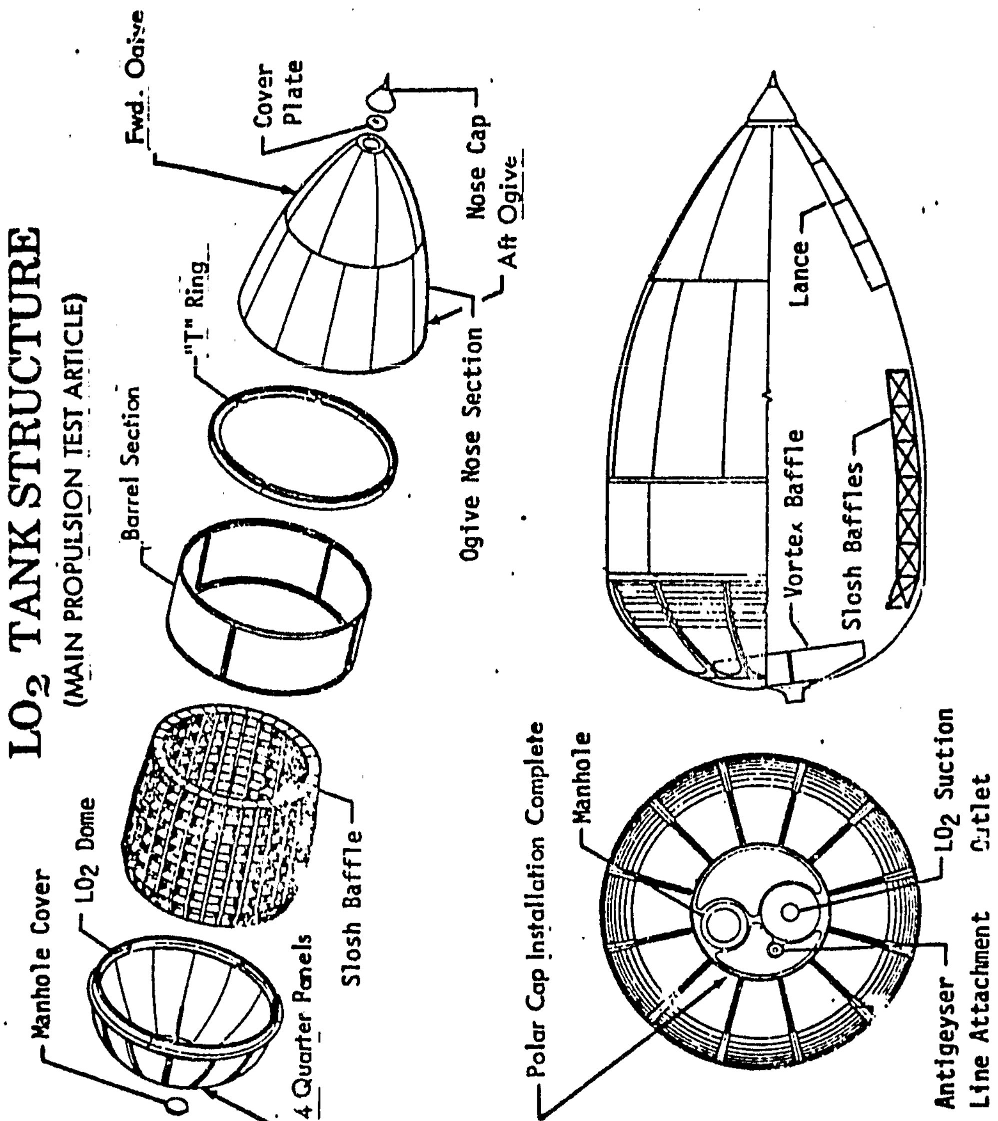

LO2 TANK STRUCTURE
(MAIN PROPULSION TEST ARTICLE)
Manhole Cover
LO2 Dome
4 Quarter Panels
Slosh Baffle
Barrel Section
"T" Ring
Ogive Nose Section
Aft Ogive
Fwd. Ogive
Cover Plate
Nose Cap
Polar Cap Installation Complete
Manhole
LO2 Suction Outlet
Antigeyser Line Attachment
Vortex Baffle
Slosh Baffles
Lance

FIGURE XII-2

LH_2 TANK STRUCTURE
(MAIN PROPULSION TEST ARTICLE)

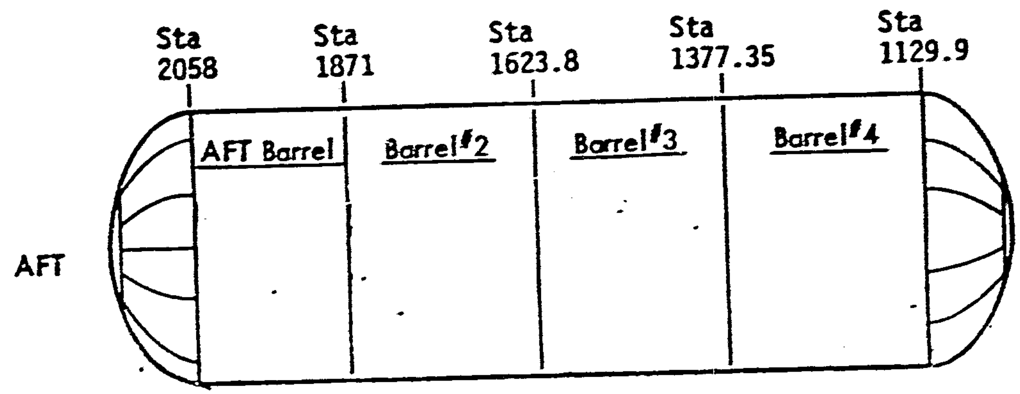
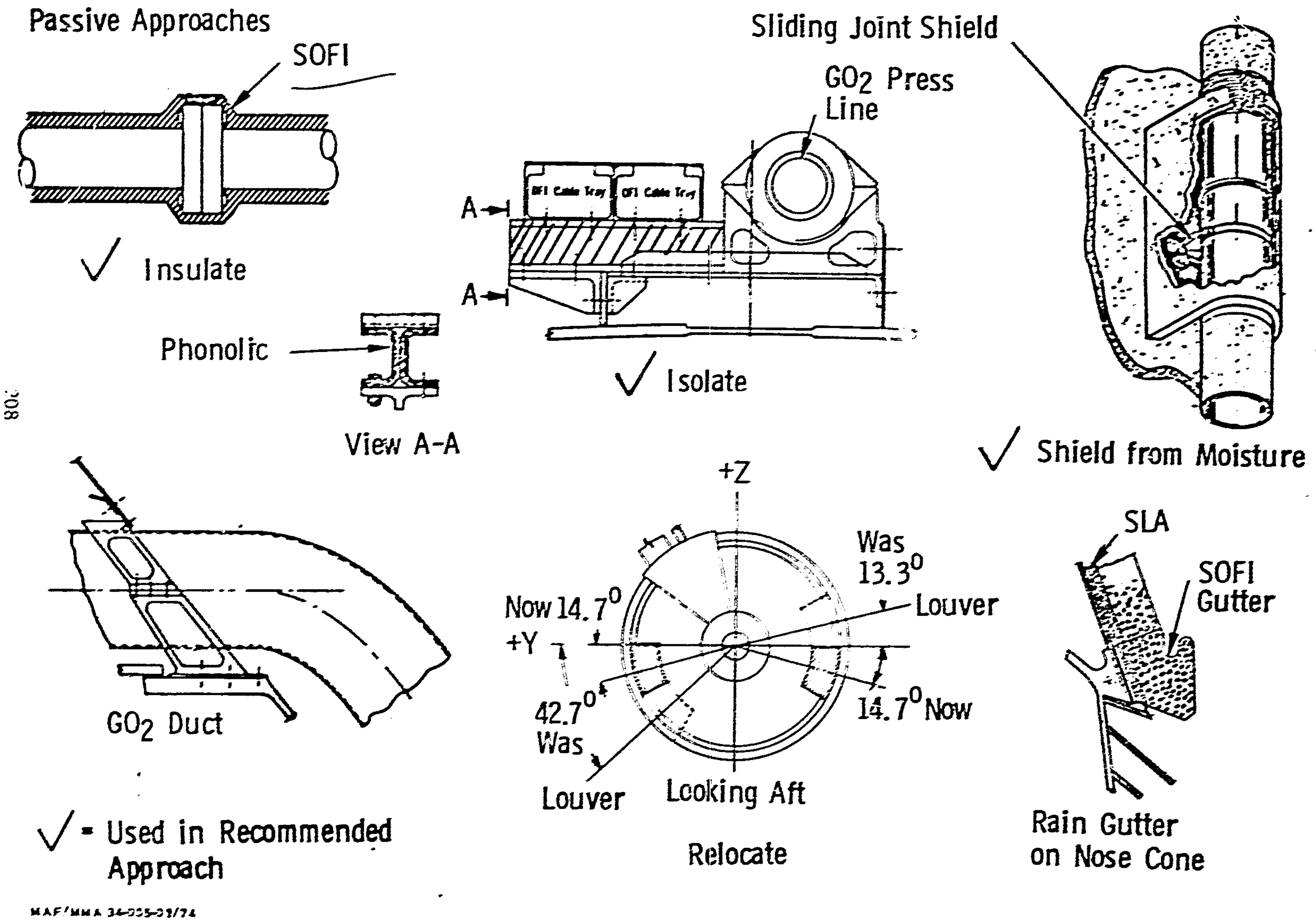


FIGURE XII-3

ICE PREVENTION/REDUCTION TECHNIQUES

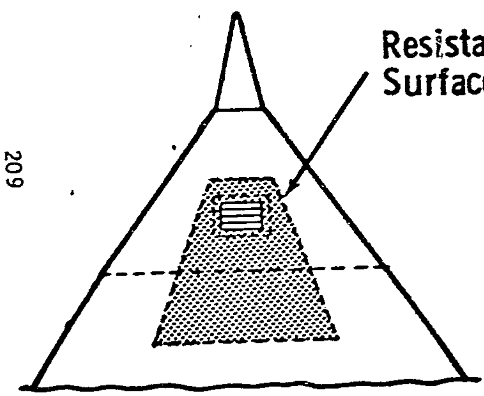
FIGURE XII-4



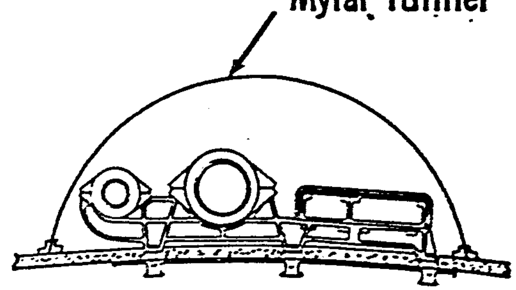
ICE PREVENTION/REDUCTION TECHNIQUES (Con't) FIGURE XII-5

ACTIVE APPROACHES

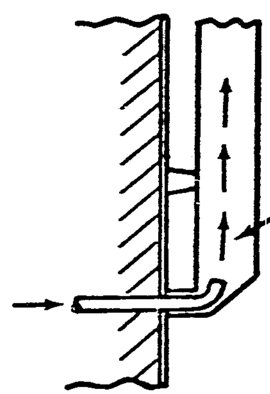
Heat (Electrical)



Inflatable Tunnels

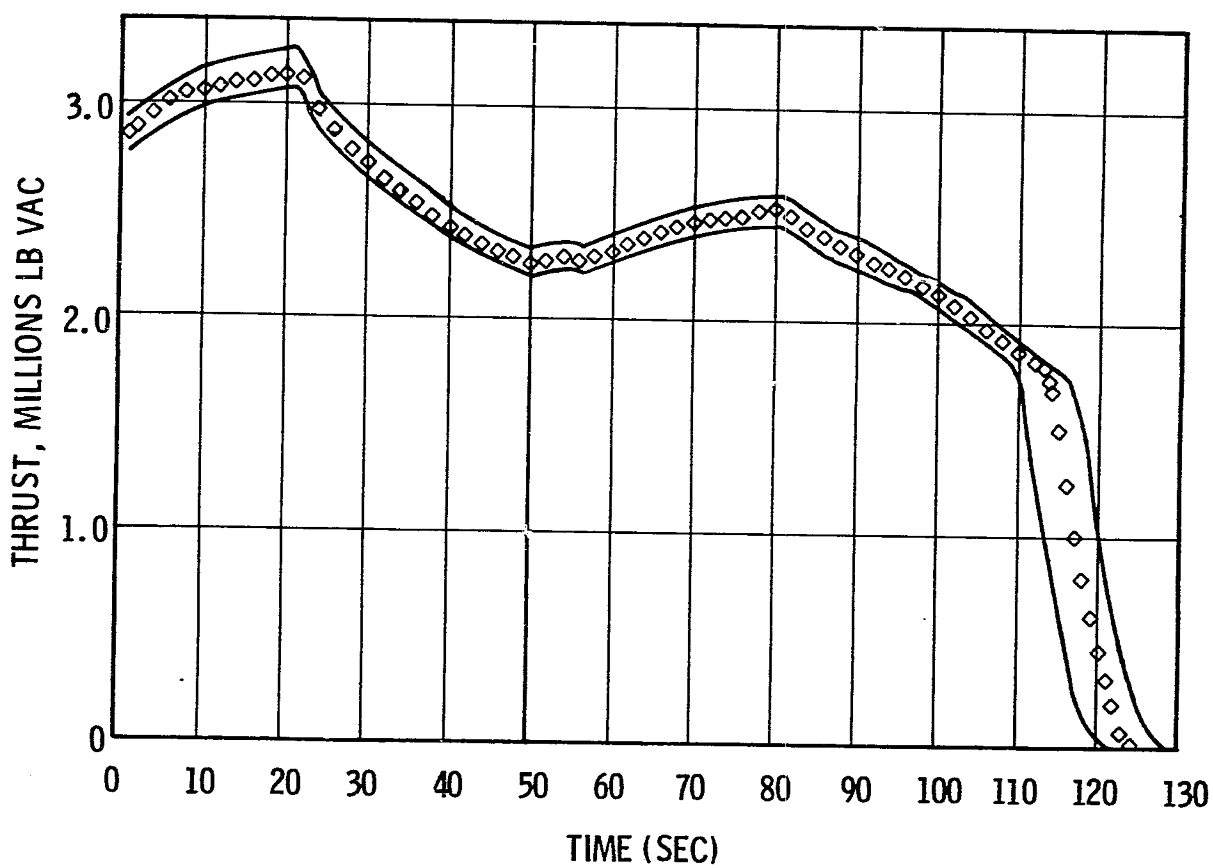


√ **Heat (Gas Purge)**



COMPARISON OF NOMINAL THRUST PERFORMANCE WITH REQUIREMENTS

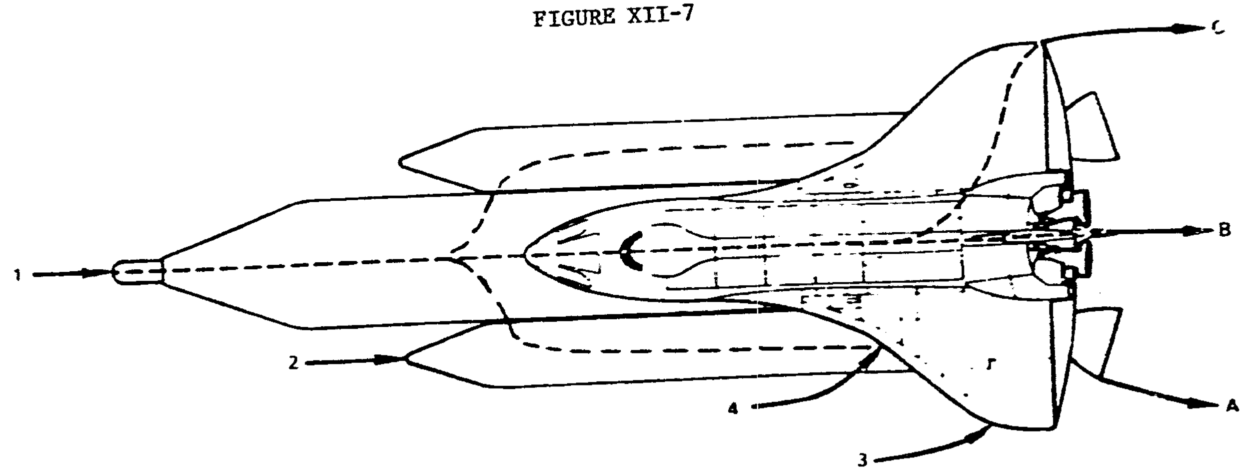
FIGURE XII-6



EL3596

ANTICIPATED LIGHTNING STROKE ENTRY AND
EXIT POINTS FOR COMPOSITE SHUTTLE VEHICLE
DURING THE LAUNCH PHASE

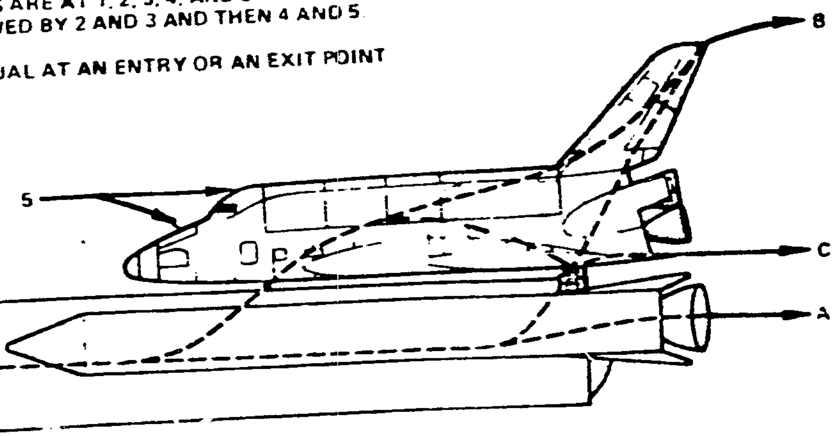
FIGURE XII-7



NOTES

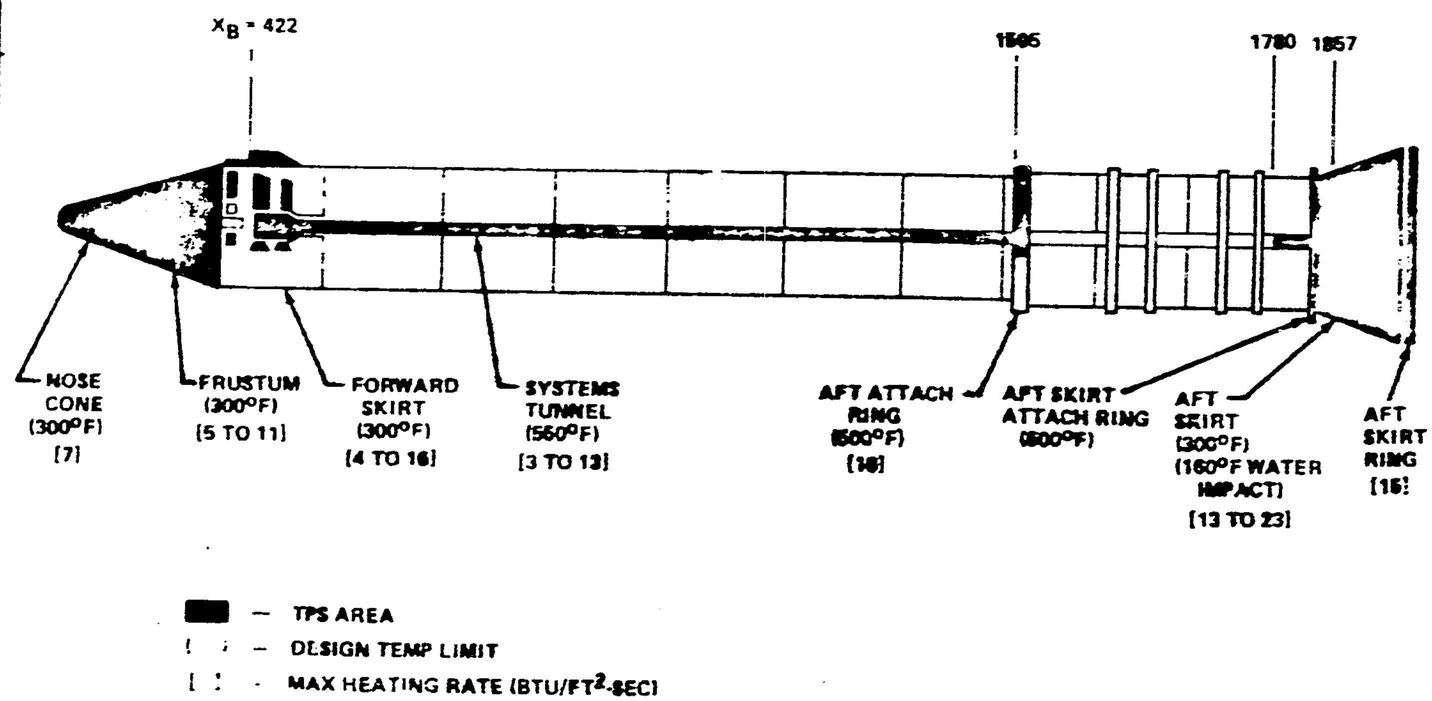
1. MOST LIKELY STROKE ENTRY POINTS ARE AT 1, 2, 3, 4, AND 5 WITH HIGHEST PROBABILITY AT 1, FOLLOWED BY 2 AND 3 AND THEN 4 AND 5.

2. PROBABILITIES OF DAMAGE ARE EQUAL AT AN ENTRY OR AN EXIT POINT



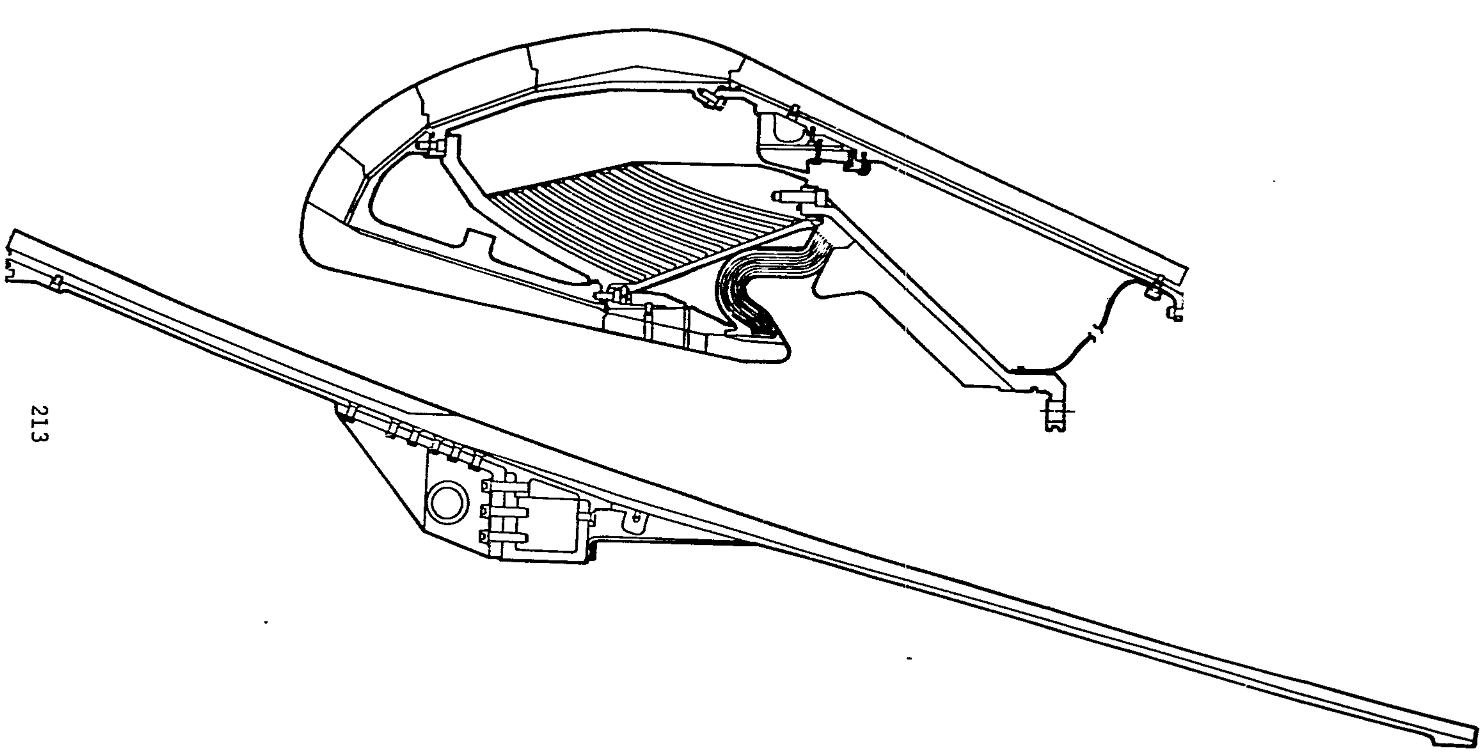
SRB/TPS PATTERN

FIGURE XII-8



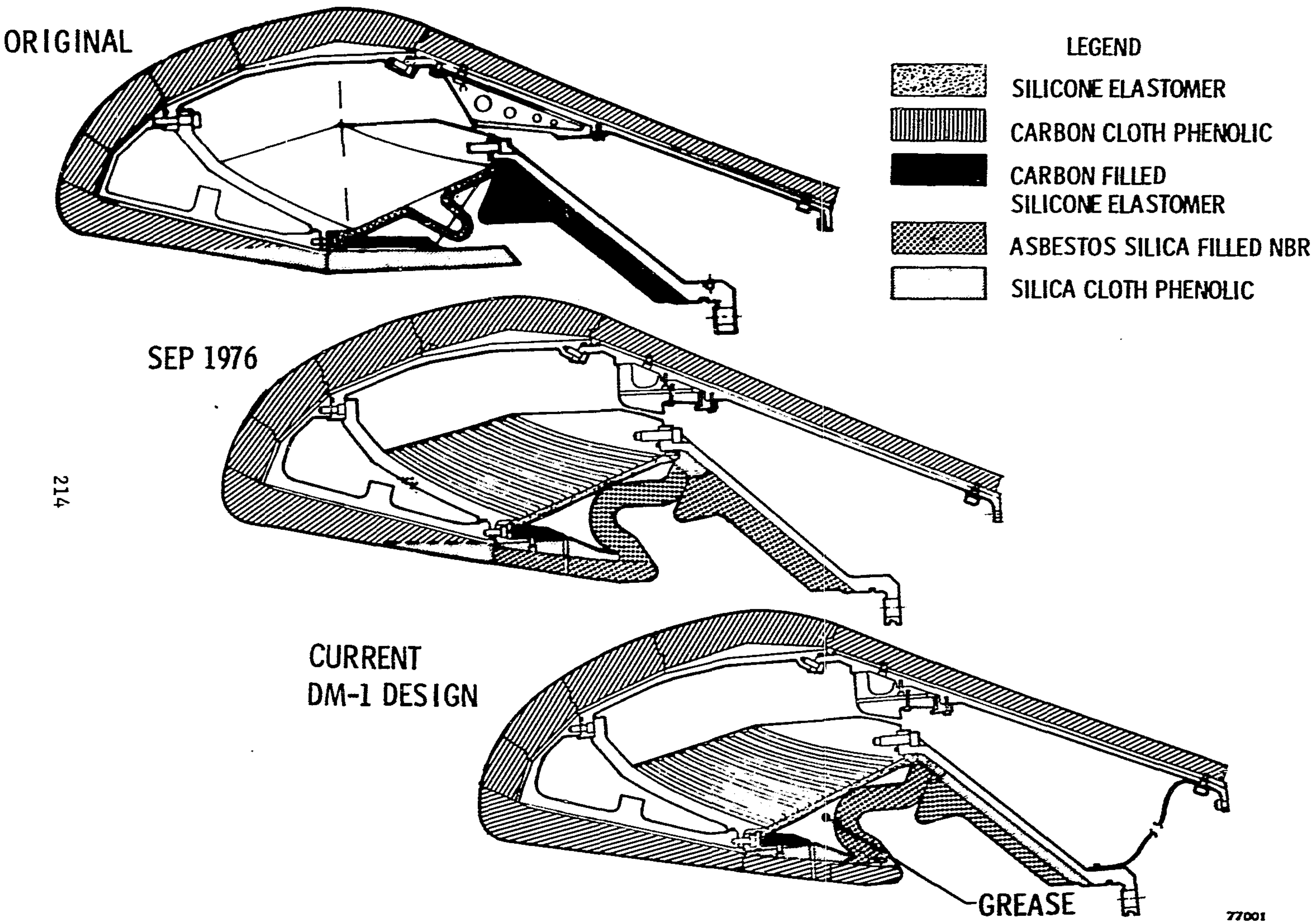
NOZZLE ASSEMBLY

FIGURE XII-9

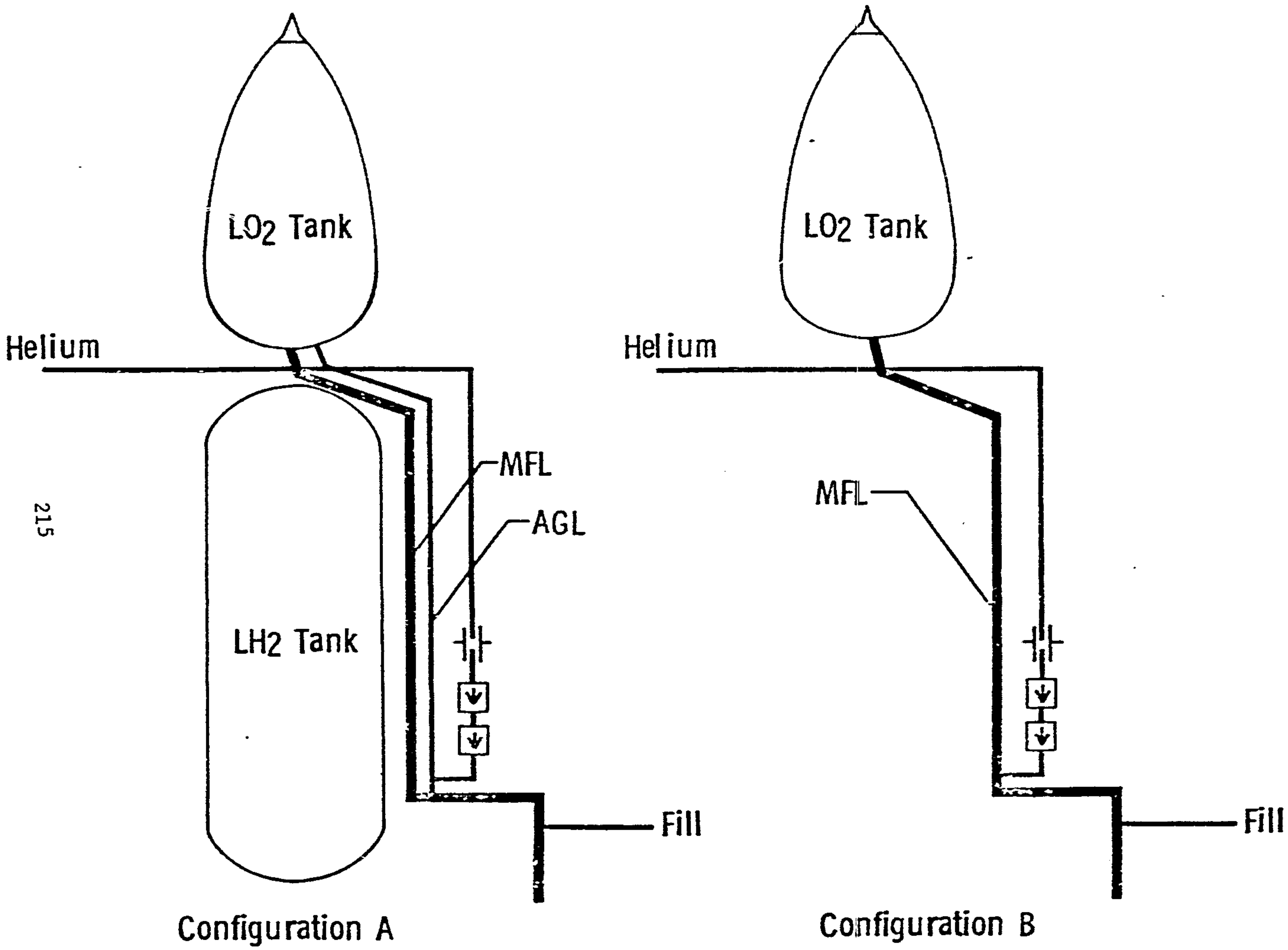


NOZZLE DESIGN COMPARISON

FIGURE XII-10



ANTI-GEYSER SYSTEM - CONFIGURATION A & B FIGURE XII-11



MAF/MMA 34 005 (05/76)

XIII. ORBITER THERMAL PROTECTION SUBSYSTEM

A. Introduction

TPS will be just flown on the Orbiter 102 although sample and simulated materials will be used on the Orbiter 101 as a part of the Approach and Landing Tests and the Vibro-acoustic test programs.

The Orbiter Thermal Protection Subsystem (TPS) has undergone a continual, albiet gradual, evolution based on the growing understanding of the aerothermodynamic performance requirements and structural qualities of both the Orbiter and the total Shuttle System. As ascent/descent trajectories and resultant isotherms and structural loads have been refined there has been concommitant changes in the TPS with regard to the coverage of surfaces with Reinforced Carbon-Carbon (very high temperature protection leading edge material), High Temperature Reuseable Insulation and Low Temperature Reuseable Insulation, and finally the use of Flexible Reuseable Insulation (RCC, HRSI, LRSI, FRSI, respectively). There have also been changes in the leading edge structural system (LESS) in terms of material thinness and type and thickness of internal insulations. Thermal seals are used to protect or seal off moveable aerodynamic surfaces, static openings, and "open-shut" one-time movement doors from the influx of high temperature gases and plasma. These have been undergoing continuing investigation, design, test and redesign. In addition to these elements, there is the SSME heat shield and the AFT thermal protection area on the Orbiter.

Beyond the design and use of the TPS there is the major job of

inspection, repair, supply and installation of all of the component parts that make up the total TPS. Each of these areas is receiving more and more attention as the design requirements and design implementation matures.

The Panel continues to monitor the evolution of this area because the system is a major advancement in the state-of-the-art and is a "must work" component of the Shuttle Program rather than because of specific current problems.

The Panel's review included inspection visits to JSC, Rockwell, Lockheed, and Ames Research Center, as well as examination of reports and documentation on TPS.

B. Observations

The table below shows the current configuration in terms of area and weight for each type of coverage.

TPS Type	Area, Ft^2	Weight, Pounds
Leading Edge Structural Subsystem, LESS (RCC)	409	3,113
HRSI	4,911	9,311
LRSI	2,857	2,256
FRSI	3,436	1,099
TOTAL	11,613	15,779

In addition to the above items there is the Base Heat Shield at the engine or aft end of the Orbiter covering 261 Ft^2 and weighing about 355 pounds as well as the thermal barriers and seals which are estimated at 1,400 pounds. Thus the total weight of the TPS as we see it today is about 17,534 pounds.

As the Outer Mold Line (OML) of the Orbiter has been defined in response to performance requirements, the thickness of the tiles has been increased and this has meant an increase in weight of about 1200 pounds.

As noted in the section on the External Tank there is a concern regarding the effect of ice from the ET impacting the TPS during the ascent portion of the mission. The concern is that after prelaunch cryogenic loading, ice may accumulate on the external tank. When the space shuttle main engines and solid rocket boosters are ignited, the resulting vibration may shake off the ice with subsequent damage to the Orbiter TPS. The recommended concept would provide ice prevention on the forward section beyond tank station 1871 through the use of electrical heaters on the Orbiter/ET forward attachment. The Shuttle Program Manager directed the contractor, Martin Marietta Corporation, to implement the recommended fixes except for component relocation. KSC was directed to continue their study to define a method of making a launch decision based on ET icing conditions.

The following summarizes the TPS data:

1. The tiles are segregated as: Class I tiles are white-surfaced and usually are 8 inches square and Class II tiles are black-surfaced and usually measure about 6 inches square. White is the LRSI and black is the HRSI. The number of tiles being produced for the program have not been fully determined as yet. Where special close-out tiles are required, usually curved or peculiarly shaped ones, the Orbiter contractor, Rockwell International/Space Division, will

machine and coat the tiles. There may be about 3,800 tiles that fit in this category. Lockheed inspection procedures use about 1% of the tiles, which is about one inspection per day on production tiles. Total tiles delivered to date are about: Class I (white coating called G036B) 980, Class II (gray with old 0005-type coating and the newer black coating) 5,000. About five arrays have been used on Orbiter 101, i.e. about 192 tiles. Qualification tests will use 1,782 tiles to be delivered by June 1, 1979. Almost 31,000 tiles are to be delivered to Palmdale for the Orbiter 102 between January 1977 and June 1978.

2. To get a "feel" for the evolution and resolution of problems the status of TPS problems defined in 1974 by the Panel are commented upon in Table XIII-I.

3. The Orbiter TPS Critical Design Review is scheduled for late April 1977, while the Orbiter 102 CDR is scheduled for August 1977. An area of interest to the Panel is whether or not the Review Item Discrepancies (RID's) in the system relating to the TPS are being followed-up to complete and satisfactory closure.

4. The TPS installation is a major area of interest because of the difficulties in obtaining and maintaining tolerances during installation and operation as well as the operational difficulties caused out-of-tolerance areas. The tolerances deal with tile-to-tile gap and step tolerances statically and dynamically. The maintenance of radii on the tile edges and between surfaces affects the radiant energy view factors for heat transfer and

associated flow patterns. There is no specification that we know of for the thickness of the tile coatings. There is a requirement for absorptivity/emissivity ration (optical-thermal properties). In examination of random tile samples, it has been determined that the coating thickness ranges between 0.011 to 0.015 inches thick (11 to 15 mils).

5. Current calculations indicate that the HRSI may very well be subjected to temperatures between 2800 F. and 2900 F. on the first OFT mission. The Ames 20 megawatt 2 x 9 tunnel can run worthwhile tests to the required energy levels. This is of interest because temperature-time, and heat load rates are critical to defining the ability of the HRSI to stand-up to these temperatures and reuse. Major concern would most likely be with the temperatures experienced in the gaps between the tiles.

6. The question of tile repair during the orbit phase of a mission has been evaluated and discarded by the program as not a viable approach.

7. Configuration management for the TPS and its tiles should be examined to assure that the as-designed, as-built and as-tested match.

8. With tile covering most of the surface, the Panel will examine the impact of radio transmissions and EMC effects, if any, on the tile coatings.

Aerothermal seals, payload bay door seals, and static thermal barrier penetration locations are shown in Figure XIII-1, 2, 3, 4 and 5. As noted before, these seals are still in the development

stage but do offer the required protection. "Life" capability would have to be proven as well.

An example of the LESS-type of assembly is shown in Figure XIII-6 which shows the fuselage nose cap assembly wherein the nosecap itself is made of RCC material. The mission life predictions analyses have shown the following minimum values for this type of nose cap configuration: *TEOS=Tetraethylsilicate over coating.

LOCATION	PLIES	T_{Max} °F	ALLOWABLE MASS LOSS, #/Ft^2	NO. OF MISSIONS Baseline Coating	Baseline Coating+TEOS*
Exterior Stagnation Point	19	2489	0.03	31	Exceeds 100
Chord Line, Exterior	19	2270	0.03	29	Exceeds 100
Windward Nosecap Lug	38	1028	0.05	11	67
Windward T-Seal Lug	19	1028	0.05	6	50
Windward Expansion Seal Lug	28	857	0.05	47	Exceeds 100

The items that would appear to not meet the 100 mission life requirement are being modified to meet the 100 mission life. A fiberglass nose cap simulation has been installed on the Orbiter 101.

The first mission in the Orbital Flight Test program (OFT) with Orbiter 102 is designed to assure mission safety by trajectory shaping to minimize the total heat load and keep the structural bonding temperature within the single mission capability of the TPS. This is accomplished by accommodating trajectory dispersions, early boundary layer transition and the performance uncertainties of the TPS itself. Such trajectory characteristics between TPS design and the expected first OFT:

PARAMETER	TPS DESIGN	OFT #1
Cross Range, NM	1,085	682
Down Range, NM	4,300	2,593
$\dot{q}_{REF}$ BTU/Ft^2-Sec	79	90
Q_{REF} BTU/Ft^2	62,520	40,219

C. Information Update

The Orbiter TPS entry heat load sensitivity has been examined to determine the effect of design and expected flight trajectories including dispersions from nominal values. The TPS, as noted, is designed to mission 3B (this is trajectory 14414.1) using nominal characteristics for material and aerothermodynamic factors. The peak structural temperatures are not to exceed 350°F and the peak strain isolation pad (SIP) outer bondline temperatures are not to exceed 500°F.

The actual entry trajectory is affected by such things as:

- Aerodynamics
- Density and winds in the atmosphere
- Guidance and Navigation parameters (velocity, angle of the Orbiter in attack and bank, rate of descent, etc.)

The nominal values associated with the design and aerothermodynamic factors can vary during actual flight due to such things as the laminar-to-turbulent flow transition time and location, the heat transfer and fluid property dispersions, tile and SIP material properties which are determined on samples such that the actual conductivity, density and specific heats will vary.

The sensitivity analyses indicate that the total heat load decreases with reduced down-range distance and consequently a lower bondline temperature. Some of the parameters that were varied included the surface roughness (17 mil used in the design and 30 mil used at the roughness trip criteria, orbit inclination (from 38° to 55°) with

launch from ETR, angle of attack of 30/40 degrees. As a result, there appears to be adequate bondline temperature margin for OFT#1 with trajectory dispersions analyzed and even with early transition from laminar to turbulent flow. Further work will be done between now and August of 1978 to assure the integrity of current analyses.

Wing-elevon aerothermal seal studies are continuing to examine additional ways to add to the confidence that the baseline design meet all the design requirements, e.g.,

1. Maintain the structure below $350^{\circ}F$
2. Withstand acoustic environment of 163 db in ascent for 8.5 minutes for 100 missions
3. Withstand a pressure differential of $\pm$ 3 psi
4. Accommodate thermal/structural deflections and a seal environment of $-150^{\circ}F$ to $+275^{\circ}F$.

The program feels that the present "blade and tube" design baseline seal system fulfills the requirements.

TABLE XIII-I STATUS OF TPS PROBLEMS DEFINED JULY 1974

RSI

PROBLEM	COMMENT
FIBER	SOLVED, JM FIBER BEING USED >$20M COST SAVINGS
COATING	
OPTICAL PROPERTIES: $\epsilon_T, \alpha/\epsilon$	
LRSI	0036B NOT DEMONSTRATED YET, ARC HAS TWO SOLUTIONS IN HAND (VHT/RCG AND GLASS OVERLAY)
HRSI	SOLVED - RCG ADOPTED
WATERPROOFNESS/CRACKING FOR 100 FLIGHTS	
LRSI	THERMAL PROBLEMS SOLVED, EITHER 0036A OR VHT/RCG WORKS; MECHANICAL DAMAGE STILL A PROBLEM
HRSI	SOLVED, RCG ADOPTED; MECHANICAL DAMAGE STILL A PROBLEM
TILE/SYSTEM DIMENSIONAL TOLERANCES	
STEP/GAP	HRSI TILE TOLERANCES CLOSE (MACHINING IS MAIN PROBLEM) LRSI TILES WARP IN THIN SECTIONS, INSTALLATION DIFFICULT AND COSTLY TO MEET, NO FORWARD FACING STEP CRITERIA
ATTACHMENTS (SIP, RTV BOND)	RI STILL HAVING DIFFICULTY MEETING TOLERANCES
SEAL CLOSEOUT	TESTS BEING PERFORMED, FILLERS BEING DEVELOPED CURRENTLY TOP PRIORITY PROBLEM
TPS REPAIR	
ON-PAD	SINGLE MISSION REPAIR LOOKS GOOD, MULTIMISSION REPAIR NOT WATERPROOF
IN-ORBIT	VERY SMALL EFFORT, APPEARS FEASIBLE, MUCH EFFORT REQUIRED

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FIGURE XIII-1 AEROTHERMAL SEALS, PAYLOAD BAY DOOR SEALS, AND STATIC THERMAL BARRIER PENETRATION LOCATIONS

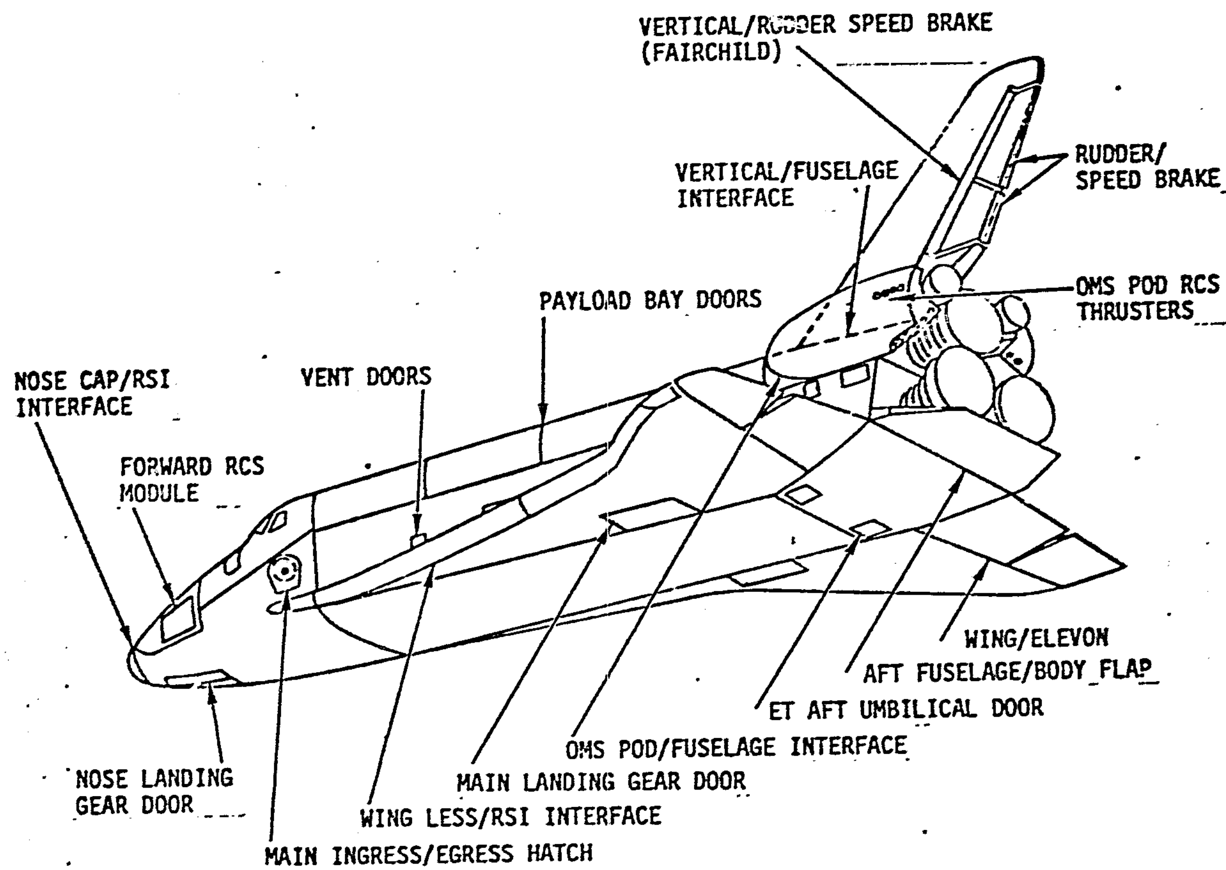

FIGURE XIII-2 WING/FLEVON AEROTHERMAL SEAL

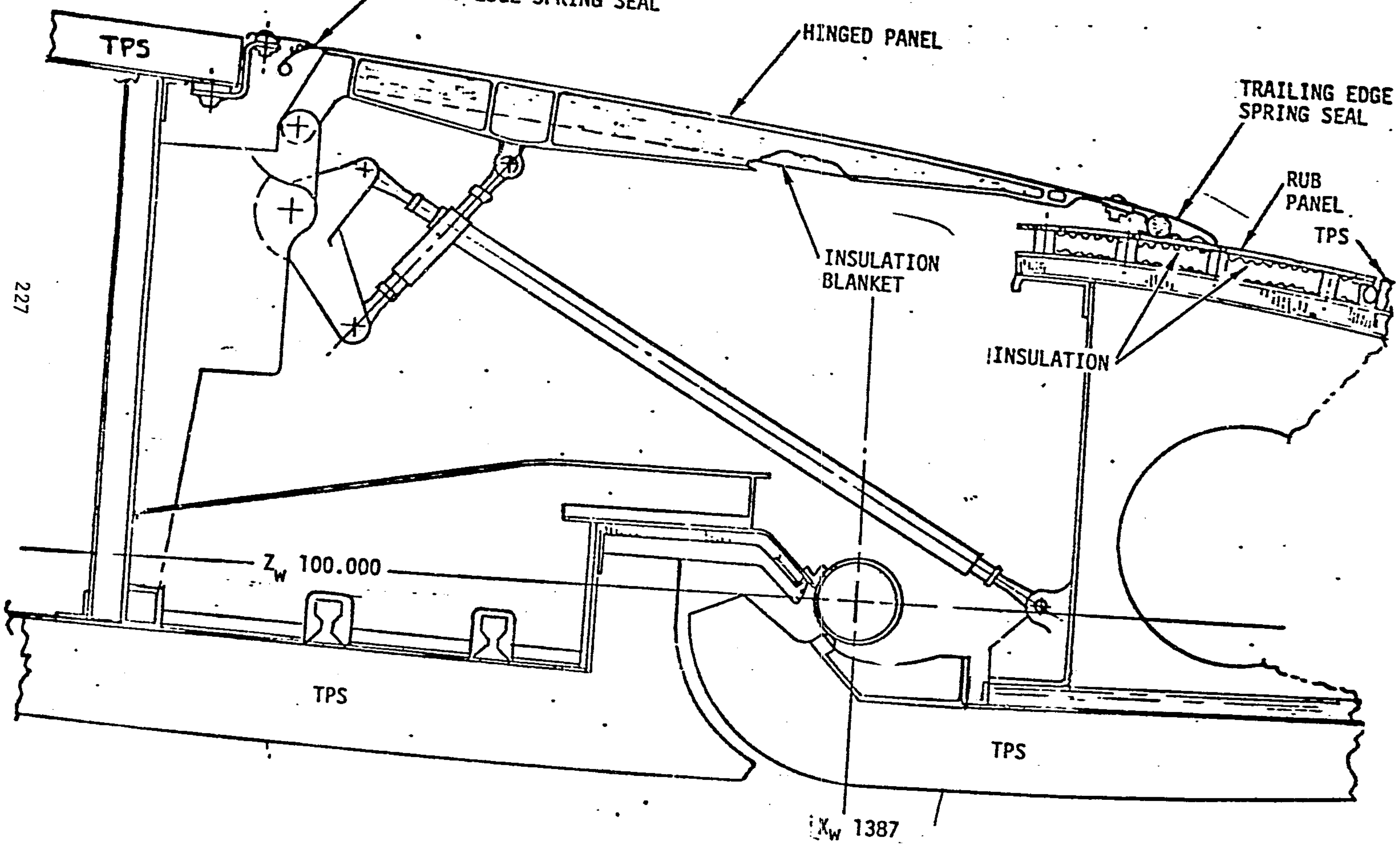

FIGURE XIII-3 PAYLOAD BAY DOOR/FORWARD BULKHEAD - THERMAL BARRIER/ENVIRONMENTAL SEAL

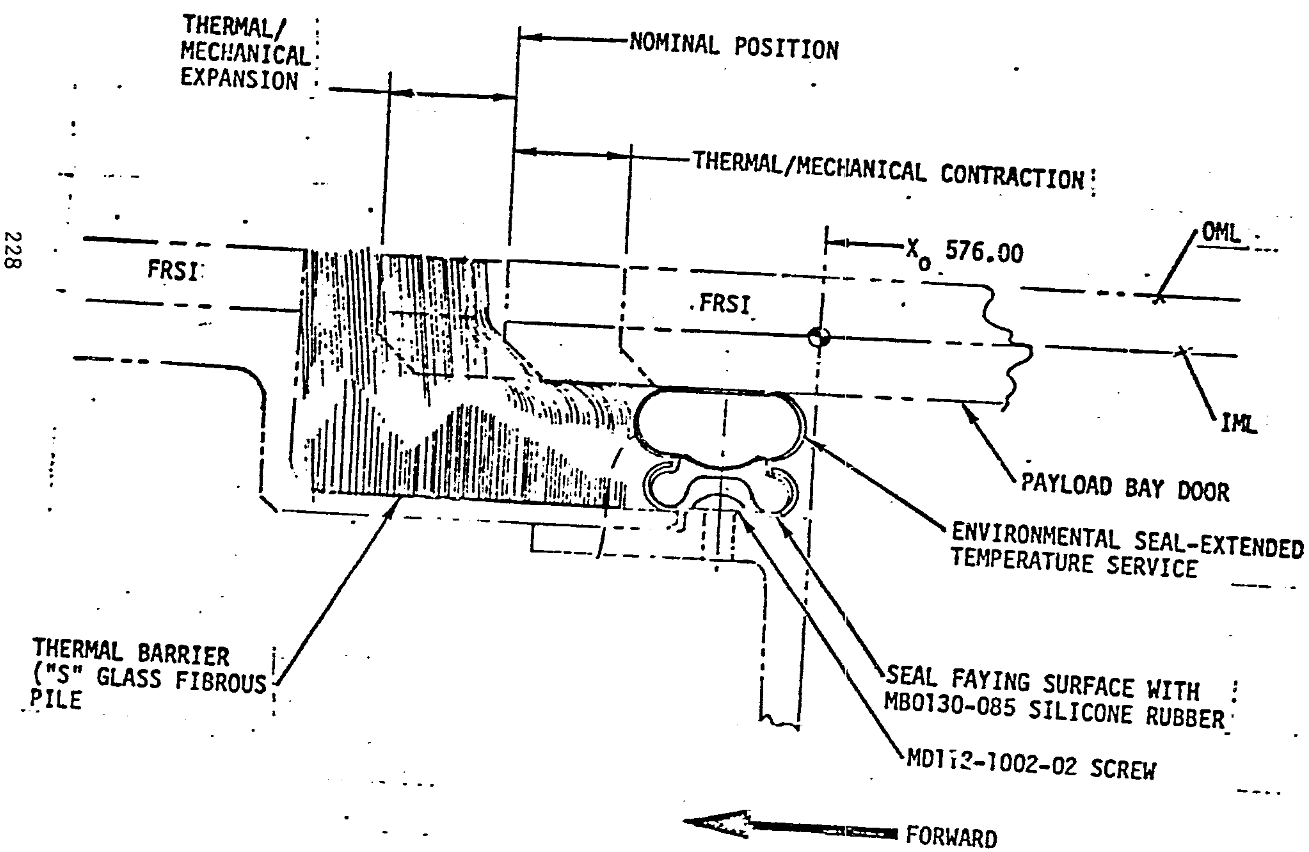

FIGURE XIII-4 (NOSE LANDING GEAR DOOR)

NLG DOOR THERMAL BARRIER

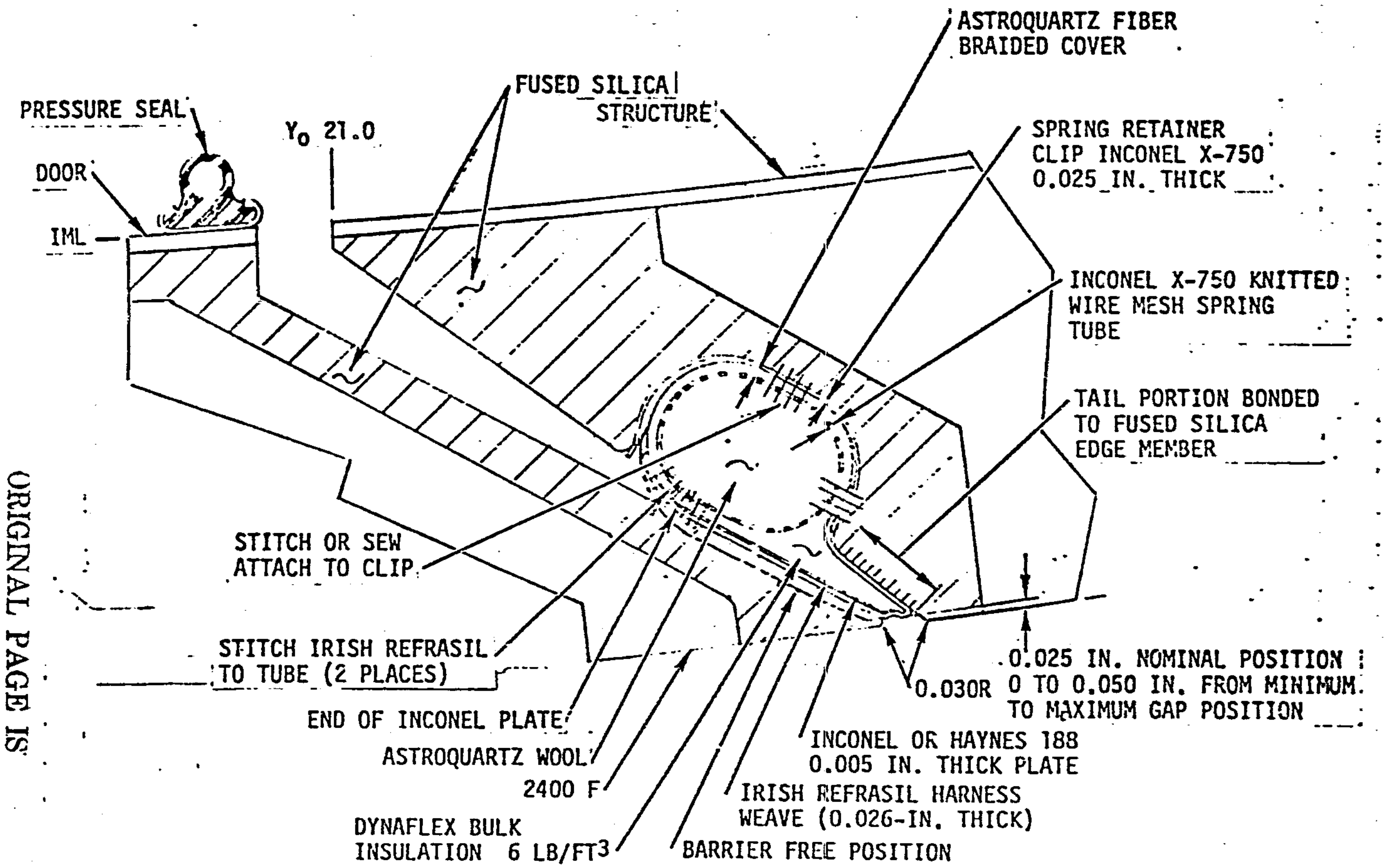

FIGURE XIII-5 HIGH PRESSURE GRADIENT GAP FILLER AREAS

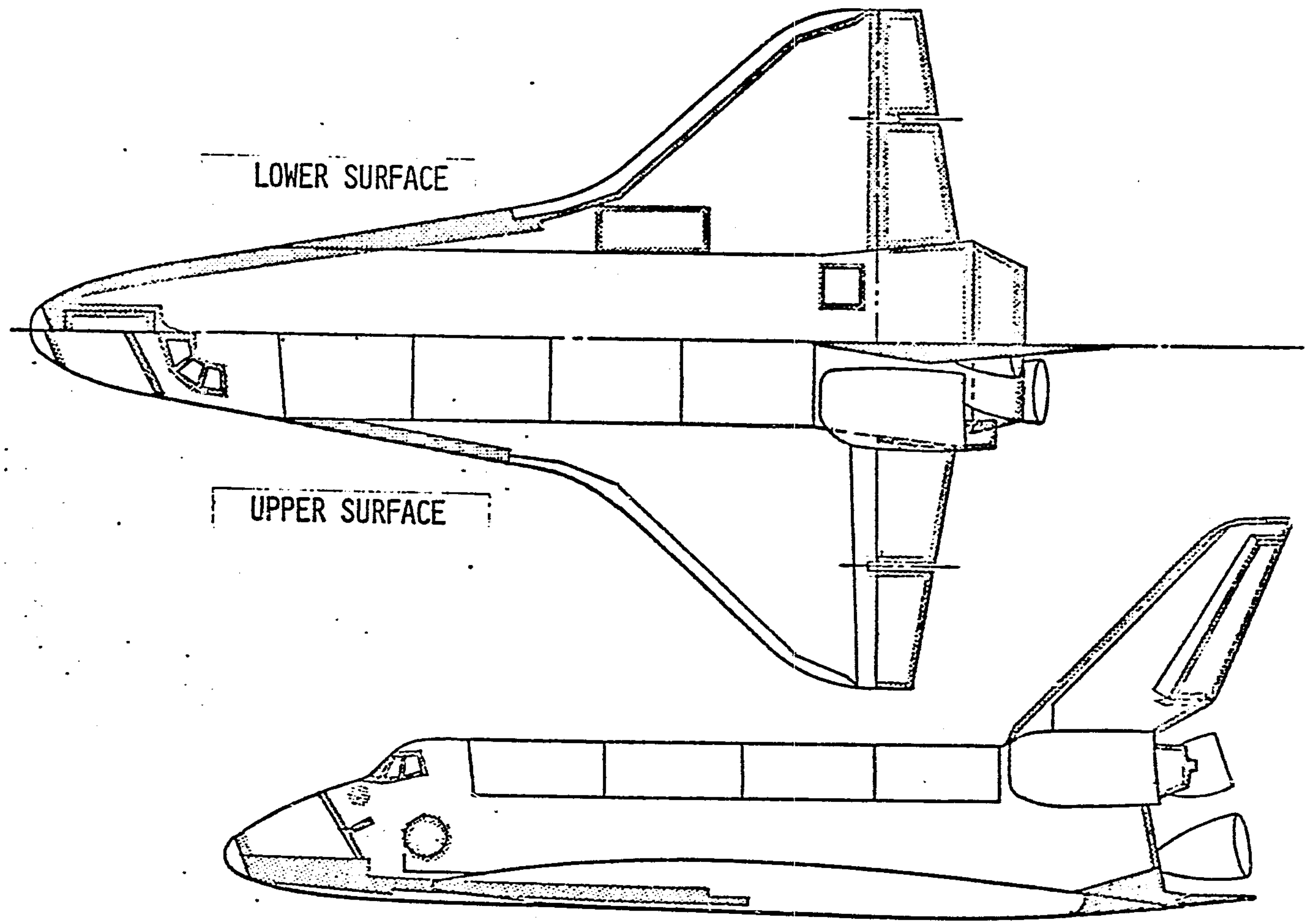

FIGURE XIII-6 NOSE CAP SUBASSEMBLY